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SILVICULTURE OF SOUTHERN UPLAND HARDWOODS

(Sixth of a Series on the Silviculture of Southern Forests)

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Sponsored by the Conservation Foundation

STEPHEN F. AUSTIN STATE UNIVERSITY
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SILVICULTURE OF SOUTHERN UPLAND HARDWOODS

Introduction

Upland hardwood types occur throughout the forests of the southern United States. Sometimes deciduous species intermingle with pines to form mixed conifer-broadleaf types; other times hardwood types are interspersed with pine types; depending upon soil, physiography, past land use, and fire. And various hardwood cover types may occur over extensive areas to the relatively complete exclusion of conifers.

While most information on southern upland hardwood silviculture deals with the Southern Appalachian Mountains and the Piedmont province, it is believed this knowledge permits much data extrapolation for areas less extensively researched. Such locales include the Interior Highlands of Arkansas' Ouachita Mountains, the Arkansas and Missouri Ozark Mountains, the bluff hills of Kentucky and Tennessee, and the Post Oak and Cross Timber Belts of Texas. The Southern Appalachian Mountains, an arbitrarily designated segment of the chain extending from Nova Scotia to Georgia, also includes portions lacking in detailed silvicultural analysis. Sufficient, however, is information on the Appalachian Plateaus, the Ridge and Valley Province, and the Blue Ridge Mountains (from west to east) to warrant inclusion here.

The management methods for hardwood forests are being severely criticized. Ofttimes the criticism is unwarranted because of misunderstanding of silvicultural techniques. Sometimes it is warranted because of misunderstanding of people preferences by foresters conducting silvicultural operations.

Yellow-poplar, for instance, requires full-sunlight and an adequate seed source for regenerating new stands. It simply won't enter the ecologic successional cycle in an understory, including its own. It is also the most economically valuable species in much of the mountains, growing fast, tall, and straight in dense, evenaged (and hence easily thinned stands). Yellow-poplar is also aesthetically pleasing, has colorful autumn foliage, and hence is significant in recreation. The forester, as silviculturist, may be correct in prescribing clearcutting to regenerate such forests and, hence, to manage wisely the resources for which he is responsible.

However, on public lands—the people's forests—wisest use currently may not be for fiber production but, rather, for aesthetics. In that case, the forester, as silviculturist, may prescribe selective regeneration harvests to produce a mixed oak-hickory unevenaged forest which will provide both low-value timber and slowly growing stems. The selection method, in contrast to the clearcut, will not leave logging slash, snags, and non-merchantable stems exposed to view. It is that exposure which gives rise to the criticism.

Silviculture includes the management of forest stands for water production, range, and wildlife as well as for fiber and recreation.

Where appropriate, information is presented. This is especially so for watershed management since the highest use for much of the hardwood forests is for production of clear (free of sediment), clean (free of dangerous microbes) water for human consumption and industrial use. Frequently, the integration of these uses will be necessary, compromising highest yield of any one use in order to obtain some benefit from other uses.

Semantics complicates silviculture in these pages. Technically, hardwoods, broad-leaved trees, and deciduous trees are not synonomous: each is precisely what the word describes. But some broad-leaved trees are evergreens (holly), some deciduous trees with broad leaves have relatively soft wood (yellow- poplar), and some hardwoods are evergreen and needle-leaved (southern pines), while most deciduous trees are broad-leaved and have hard wood (oaks, hickories). In practice, however, the terms are used interchangeably.

SOUTHERN APPALACHIAN MOUNTAINS AND PIEDMONT

Information is not available to provide specific silvicultural recommendations for the several physiographic provinces within the Appalachian Mountain region -- Blue Ridge, Great Smoky and other highlands, Valley and Ridge province, and Cumberland Plateau. However, for this predominantly hardwood region, and for the Piedmont, specific conditions will be presented where evident. Material pertaining to conifer silviculture is also given where desirable for comparisons and contrasts with deciduous species. This bulletin should be used together with Bulletin 18 of this Series on the Geography of the Forests of the South (Walker and Collier, 1969).

Aside from the chestnut disaster caused by *Endothia parasitica*, Southern Appalachian forests not only have, but to a large degree are, an "overburden" of wolf, diseased, and unmerchantable stems. Wildfires, unfavorable cutting practices, grazing, and browsing by wildlife have left woodlands depleted of the high-value timber once prevalent. But, ever increasing markets even for this overburden are now permitting some semblance of at least extensive silviculture. Shrubs and vines must be replaced with trees to improve the composition and growth of stands and salvage cuts are needed to remove defective stock, but it may be necessary to carry over some stems for "Sweetening" later harvest. [1] Yellow-poplar stands are an exception, coming in on small, moist, abandoned fields to form a pure, evenaged, and usually dense type.

Wood quality is especially important in hardwood forestry. Premium prices considerably above those for "bridge timbers" are paid for logs yielding much face veneer for furniture. Wood quality is controlled by the silviculturist in the regulation of diameter growth which, in turn, is controlled by stand density. Production of high grade material is also encouraged by limiting branching and the consequent knots on the face. Pruning of normal and epicormic branches and the avoidance of the development of epicormic branches through stand density control are other means.

Growth

Virgin deciduous forests have been virtually exhausted except at the highest elevations, and the supply of second-growth is scarcely sufficient to support a timber industry. Logs are small, grades are low, and manufacturing costs per unit are high. Most sites are inhabited by unevenaged coppice stands of oak-hickory types supporting a dozen cords per acre and annually growing 1/3 cord per acre. Second-growth merchantable timber produces about 200 board

[1] Further details for rehabilitating depleted Appalachian hardwood stands are reported by Wahlenberg (1953), Jemison (1946), Auten (1935), and Minckler (1946a, 1946b).

feet per acre annually. Volumes for typical stands, with about 30 percent stocking, are about 3.5 MBM, and mean annual growth usually peaks at ages of 60 to 80 years in full stands with SI 60 (Campbell, 1954; Wahlenberg, 1956). Trimble (1960) found 10-year dbh growth rates ranging from one-half to 2.6 inches, depending upon species and site quality.

Pines enter dry old-fields, usually initiating succession on sites for which deciduous species may be best suited. Such stands have low volume—less than 1.5 MBM per acre with annual growth seldom exceeding 100 board feet per acre. If intensively managed, these sites could support pine stands of up to 10 MBM per acre.

Sycamore trees on soils of an old lake bed have grown to heights of over 80 feet in 20 years, indicating the site index is above 100. Another 17-year-old stand had 2.3 MBM plus 12 cords per acre, an average dbh of 9 inches, and heights of 70 feet. At age 22, that stand yielded 10 MBM per acre (Doolittle, 1956; and Sluder, 1959).

Seasonal Growth

In general, radial growth of hardwoods starts after leaves are full-grown and is completed by late August (Jackson, 1952). The grand period of growth is generally less than for conifers and varies among deciduous trees. The time of initiation of growth appears to be influenced by late winter temperatures (Fraser, 1958).

Deciduous trees make height growth according to the amount of carbohydrate produced in a year, rather than depending upon the current-year's photosynthesis. This is evidenced by most height growth occurring in early spring before foliage, the photosynthesis "factory" has developed. Trees stop growing in summer, after which leaves carry on photosynthesis for carbohydrate storage. Dogwood and other species with longer seasonal growth probably use current-year's carbohydrate (Kozlowski and Ward, 1957).

Increasing day length apparently increases the growing season for a number of hardwood species (Kramer, 1936; Downs and Borthwick, 1956). Cold air masses with below-freezing temperatures in spring reduce ring width through foliage injury, especially for American beech (Tryon and True, 1966).

Frost following cambial activity initiation may result in false growth rings (Glock, 1951). False growth rings are a problem with magnolia, especially on wet sites, for which there is no known way to differentiate between these and true rings, even microscopically. Branch whorl numbers are not a reliable means of estimating age of this species (Flanders, 1950).

Shade and Sun Organs

Shade leaves of deciduous trees are thinner, have greater surface area, thinner epidermal walls, less palisade layers, and cells of the palisade layer are thinner than for sun leaves of the same plant (McDougald and Penfound, 1928). Shade leaves also have less supportive and conductive tissues. Stems in dense shade are thinner, internodes are longer, the percentage of pith is greater, and the proportion of xylem is less. Therefore, shade stems are less xeric than sun stems.

Site Index

Preliminary site index comparisons reflecting the height growth of various Southern Appalachian and Piedmont species are given in Figures 1 and 2. At age 50, white pine is superior to all other Southern Appalachian species except on land above SI 105 for white pine. On the better sites, yellow-poplar has the greatest growth rate for the first 50 years and is most responsive to changes in site among the species tested.

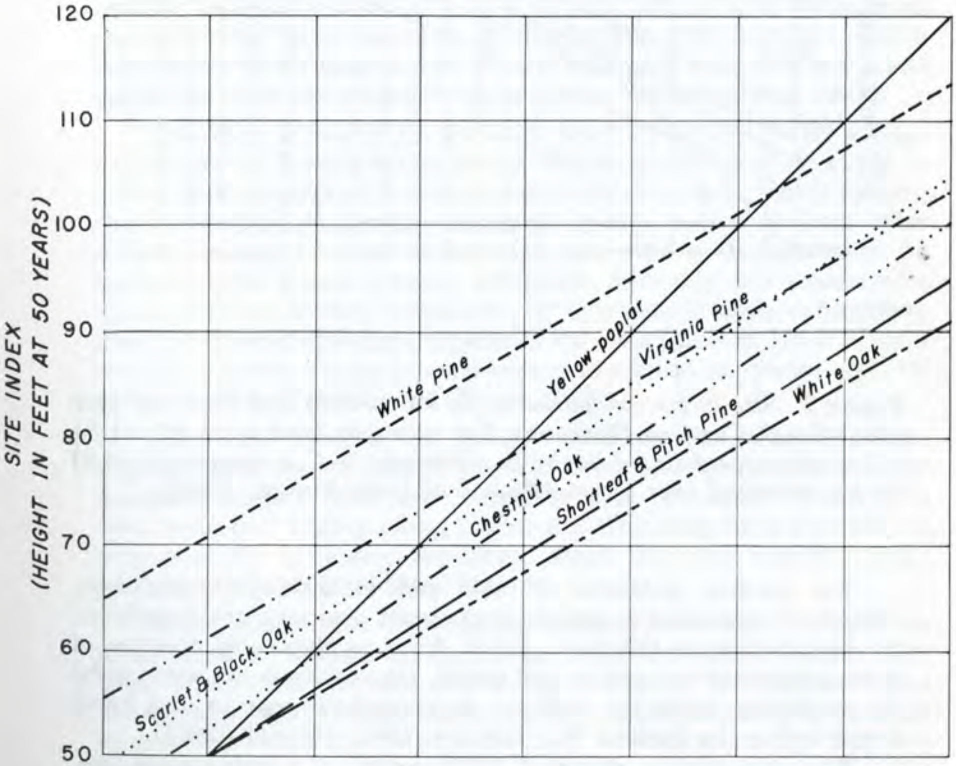

Figure 1. *Comparison of site indexes for various species on the same land in the Southern Appalachians. For example, land of SI 90 for white pine averages SI 80 reading down and across for yellow-poplar and SI 70 for shortleaf and pitch pines [from SEFES].*

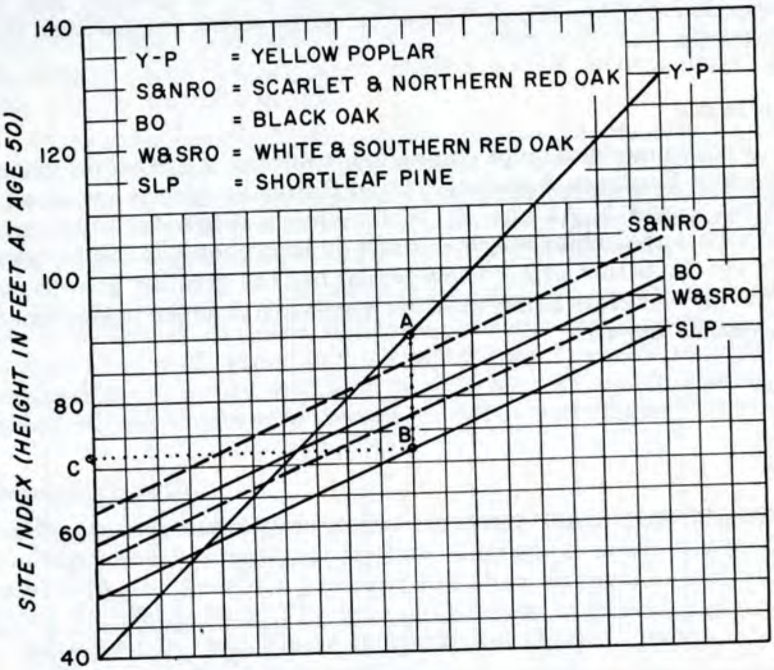

Figure 2. *Site index comparisons for hardwoods and shortleaf pine in the South Carolina Piedmont. For example, land of SI 90* [*A*] *for yellow-poplar, reading down to B and across to C, averages about SI 72 for shortleaf pine* [*from Olson and Della-Bianca, 1959*].

For growth potential of oak and yellow-poplar seedlings, immediate past growth and present crown positions are considered the best indicators (Walters, 1963). And, as slope and position of slope percent are related to soil depth, these criteria are also useful for predicting oak site quality: northeasterly aspects and lower slopes being the highest SI (Trimble, 1964; Hannah, 1968).

The economic importance of yellow-poplar as a replacement tree for American chestnut and agricultural cropping on better sites has stimulated site indexing techniques for this species. Phillips (1966) found depth to mottling, depth to tight subsoil, clay content of the subsoil, topographic position, and surface soil drainage accounting for two-thirds of the variation in SI. For the southern Appalachian Mountains:

$$\text{Log SI} = \text{Log Ht. (feet)} - 9.158\ (1/50 - 1/\text{Age})$$

Regeneration

Natural

As a generality, cutting methods to obtain either evenaged or all-aged forests have not been determined and, as Wahlenberg (1953) points out, there is no urgent need for resolution of this fundamental problem. Depending on present stand conditions, costs, and expected growth response, these depleted stands may be (1) clearcut and planted, (2) clearcut and allowed to coppice, or (3) partially cut to remove the most inferior stems in order to encourage, perhaps, species and form of potential merchantability.

Methods of cutting influence growing stock and the volume growth by size groups. For instance, after 20 years, light cutting resulted in more than twice as many good timber trees as did heavy cutting, an equal number of good poles, but considerably fewer good saplings. The latter probably is due to the little sunlight which reaches the forest floor in light partial cuts and, therefore, few seeds germinate and few dormant buds sprout (Frothingham, 1943).

Selection harvests are recommended for stands with a high proportion of good trees or poles. Where good growing stock is scarce, but saplings of favored species are abundant, heavy cutting should be done. Generally, desirable species hold their own after cutting except in pine-hardwood types where conifers may be replaced with brush sprouts. Although desirable and undesirable species follow selection techniques, development is likely to be slower than for clearcut openings, especially for oaks (McGee, 1966). Crown extension into openings in such stands is related to species and, for most, is slow (Trimble and Tryon, 1966).

Seed-tree cutting is often effective in the Southern Appalachians. In one case, 10 years after harvest, more commercially desirable species occurred thereafter than in areas receiving a "conventional" high-grading timber cut. This may have been due to deer mortally browsing seedlings, since the area conventionally harvested afforded wildlife cover.

Clearcutting not followed by cultural treatments results in invasion of wild plum, hawthorn, and staghorn sumac. Fortunately these inferior species fade out as the canopy of the coppice forest closes. Although partially cut and uncut stands do not greatly differ in quantity or quality of reproduction, with clearcutting there are nearly twice as many seedlings per acre as otherwise. Roughly one-half of the seedlings are of heavy-seeded species, regardless of the degree of cutting. Most new seedlings occur where the original forest was heaviest, perhaps because seedbeds were more completely scarified in logging or because of less underbrush and herbaceous competition.

Optimum distribution of trees by stem diameter after cutting is always considerably less than the biological maximum and, as computed by Wahlenberg (1956), provides a basis for allocation of cutting budgets (Fig. 3). The line of silvicultural optimum is designed to represent the balanced distribution suitable for long-term selection management. In the case illustrated, lightly cut forests resemble the management optimum 15 years later; and even then, the number of small-size trees exceeds the desirable number as it also does for heavily and moderately-cut forests. Heavy cutting destroys the all-age balance in size distribution of a climax forest and promotes development of an evenaged forest. At the same time, diameter growth increases with decreasing stocking of residual stands down to about 20 percent of maximum stocking. All-age silviculture, of course, requires that stands be kept below their biological equilibrium in order for growth of adequate interest rate to be obtained.

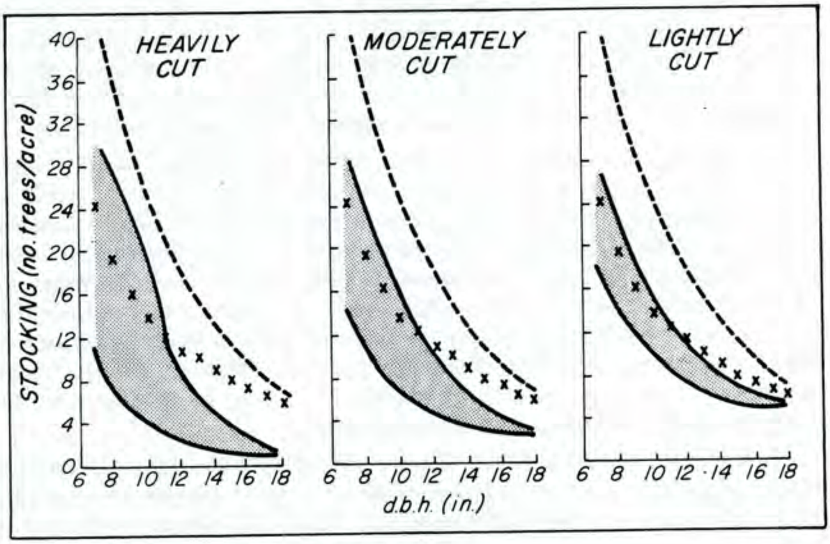

Figure 3. *Shaded areas show average changes in actual diameter distribution 15 years after cutting compared with the biological maximum [dash line] and management optimum [X line] distribution. The X line, necessarily tentative and somewhat arbitrary, is designed to represent the balanced distribution suitable for long-term management for sustained yield [from Wahlenberg, 1956].*

After the partial cutting of an upland hardwood stand, 15 thousand seedlings per acre germinated, over one-fourth of which were sugar maple, another one-fourth white ash, and 10 percent yellow-poplar. Sugar maple, being more tolerant of shade than the other species, suppressed to extinction the ash and yellow-poplar on the site. At the time of cutting, sugar maple was strictly an understory component contributing 13 percent to the basal area, but after 32 years it accounted for one-third of the basal area. Red oak, while not a prolific seeder, maintains its position and is better formed than sugar maple. To obtain a favorable seedbed for oak reproduction on sites with thin droughty soil, it is necessary to destroy the understory when its chief component is poorly formed sugar maple (Williamson and Sander, 1957).

Sweetgum reproduction cannot depend upon air-borne seed. With winds up to 25 mph, 96 percent of the seeds land within 200 feet of the seed tree. Rarely are they scattered more than 600 feet (Guttenberg, 1952). Where the site is satisfactory for sweetgum, seed trees should be retained at distances no greater than 100 feet, permitting a margin of safety as forests reduce wind velocity and impede seed flight.

Tree Grades - Tree grades aid silviculturists in selecting stems to leave or to cut, based upon an understanding of the combination of volume and quality increment for particular sites. Campbell (1951) provides a method for choosing a leave-tree among yellow-poplar, buckeye, basswood, white oak, and northern red oak, all of grade A quality and 20 inches dbh (Fig. 4). Basswood is the most valuable of these species and buckeye the least. But, if there is a choice between red oak, white oak, or yellow-poplar, the rapid rise in value of white oak on the curve beyond 25 inches suggests this species be retained if

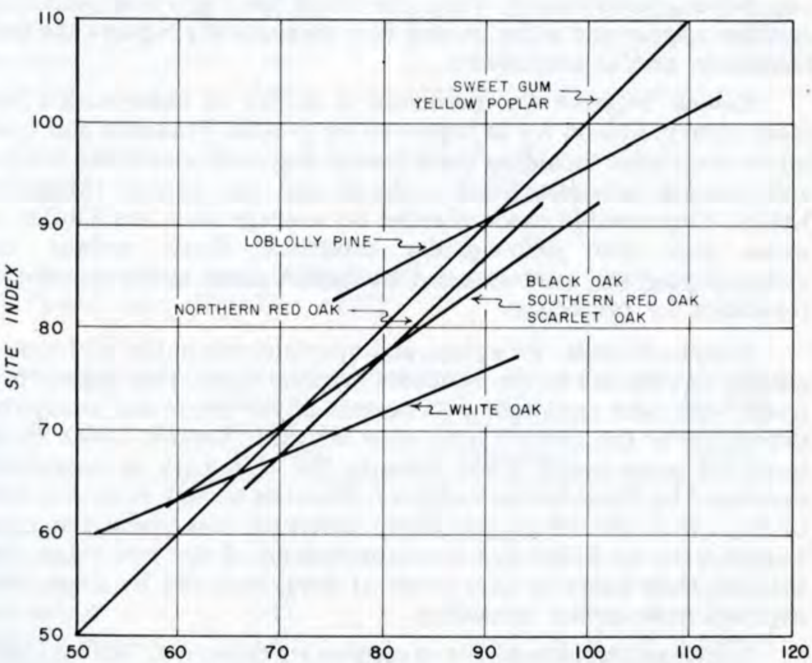

Figure 4. *Comparison of site indices for several species on same land in Georgia Piedmont* [*after Campbell, 1951*].

leave-trees are to remain for 20 years or more and if growth rates for the various species are similar and fairly constant. Stems of lesser quality than grade A have different curves for various species (Campbell, 1951), but the variation in value between them is not nearly so great and, for the present, not important in selection.

Animal-Seed Relations - Birds provide for better seed germination. They hasten the breaking of dormancy by reducing the thickness of seed coats through abrasive action within the gizzard in the presence of juices and bacteria. Seed coats are then more permeable to water and, perhaps, oxygen. Birds, however, are not as effective as sulfuric acid treatments (Krefting and Roe, 1949). Seed is apparently not benefitted by digestion in mammals, but many which pass through the alimentary canal remain germinable and these animals, therefore, are an important means of dispersal.

Plants for which birds are important seed distributors include cherry, blackberry, sumac, persimmon, and hawthorn—all with fleshy fruit. Where fields adjoin forest edges and flood-plains—habitats rich in birds and fruit-bearing plants—shrubs are apt to develop to a greater degree than where fields are surrounded by stands of young pines. Well-terraced fields succeed to shrubs because birds and rodents carry sumac and persimmon to the terraces the year before abandonment. Thus, the brush has a one-year head start on other species and in the second year may quickly capture the field (Johnston and Odum, 1956).

Robins improve the germinative ability of honeysuckle and black cherry. Poison ivy is improved by grouse. Pheasant and quail injure some seed, including black locust, dogwood, and choke cherry; and rodents consume black walnuts and oak acorns (Minckler, 1946b). Unprotected seeds planted on average sites are limited to white pine and yellow-poplar mixtures. Black walnut and yellow-poplar are recommended on better sites, using screens or repellents for protection.

Coppice Stands - Fire plays an important role in the initiation of coppice oak forests in the Southern Appalachians. Fine stands may result with oaks comprising 85 percent of the stems and occupying two-thirds of the ground area after 8 years (Keetch, 1944). Small trees are most easily killed because the thin bark is completely enveloped by flame fed by leaf litter. Fires hot enough to wound trees in the 1-inch dbh class will likely surround and girdle the stem. Larger trees are killed due to accumulations of dry fuel other than litter at their bases or to a series of fires, each fed by dead wood exposed from earlier wounding.

Clear-cutting also results in coppice reproduction. McGee (1968) found the number of stems from one source related to inheritance. Others note that sweetgum sprouts, whether occurring on roots of living or cut trees, remain entirely dependent upon parent root systems for support, nutrients, and water. Consequently, long-term existence of such stems—20 to 50 parent tree—is jeopardized (Kormanik and Brown, 1967).

Planting

Southern Zone - Successful planting in the region is dependent upon precipitation and consequent soil moisture. For old-fields in the Great Appalachian Valley,[2] mortality and first-year growth is strongly affected by (1) rainfall the first season after planting, (2) aspect, (3) slope steepness, (4) friability or plasticity of subsoil, (5) rodents, and (6) density of competing vegetation (Tables 1 and 2).

Table 1. *Average Height Growth in Feet of Plantations as Affected by Consistency of B Soil Horizon* [*after Minckler, 1943*].

	Friable B horizon		Plastic B horizon		Stiff B horizon	
Species	Wet-year plantings	Dry-year plantings	Wet-year plantings	Dry-year plantings	Wet-year plantings	Dry-year plantings
Shortleaf pine	——	2.42	2.59	2.41	2.10	2.72
White pine	1.80	1.41	1.49	1.33	0.75	1.08
Yellow poplar	1.45	1.62	1.28	0.79	0.73	0.26
White ash	1.03	0.91	0.58	0.40	0.43	0.20
Red gum	——	——	0.73	0.40	0.55	0.27

Table 2. *Average Annual Height Growth in Feet of Plantations by Soil Types* [*after Minckler, 1943*].

Species	On soils derived from dolomite	On soils derived from limestone	On Soils derived from shale
Shortleaf pine	2.45	2.41	1.14
White pine	1.44	1.20	0.88
Yellow poplar	1.12	0.72	0.80
Black walnut	0.17	0.15	0.55
White ash	0.47	0.47	0.85
Red gum	0.41	0.60	------

[2]Areas of the Great Appalachian Valley may be so filled with even-topped ridges as to be a mountain and not a lowland.

Many species are planted: shortleaf and white pines as well as northern red, black, southern red, chestnut, and bur oaks; yellow-poplar; black walnut; white ash; and sweetgum. Of these, all the hardwoods and white pine, in contrast to shortleaf pine, are seriously affected by relatively low moisture. While shortleaf pine is the least sensitive[3] of these species to site conditions, it is most sensitive to shade of competing vegetation.

Minckler (1946b) recommends shortleaf pine for hardwood sites by first making a hole in the canopy twice as wide as nearby trees are tall and then interplanting.

Checkerboard mixtures as well as rows, are also suggested. Squares with from 9 to 25 trees of a species rather than random mixtures prevent early overtopping of slow starting kinds, although species used should have growth rates about equal for the particular site. However, severe edge effect may occur in later years if one species attains a slight advantage over another. Slow growth of white pine is to be expected the first few years, especially on dolomitic soils with stiff *B* horizons.

Sweetgum is also a xeric tree in this region, and able to withstand droughty ridge conditions, soil moisture having little effect upon plantation survival. On dry sites, however, sweetgum form is poor and trees rarely reach currently commercial grades for lumber.

Rainfall during the year of planting affects plantation successfulness. It is manifested in the *B* horizon, as imperviousness increases with heavy rains, drainage becomes poorer, and soil aeration diminishes.

In sites with friable subsoils, yellow-poplar, for instance, does about as well in dry years as in wet years, but in plastic soils, dry-year growth is only 12 percent of wet-year growth.

Summer droughts in the Southern Appalachian Mountains result in early foliage browning and leaf fall. Droughts as severe as one-fourth normal rainfall are reported. Although for trees on good sites, where available moisture is not extremely deficient, recovery occurs the next year, mortality on ridges is high, and those stems which survive commonly develop stagheads. Decreased vigor then permits invasion of secondary agencies, such as the shoestring fungus, two-lined chestnut borer, and long-horned beetle, that eventually kill trees. Because root restriction in shallow rocky soil of the ridges hastens drought damage, mesic and hydric species should not be planted on upper slopes. As a consequence of differing moisture tolerances, less desirable species are more abundant on dry than moist sites, making up three-fourths of the reproduction on the dry areas and one-half on moist sites (Wahlenberg, 1956).

North-facing shale slopes may be planted to yellow-poplar, black walnut, and white ash. Except for shortleaf pine, which is not

[3]On former hardwood sites in the lower part of the Tennessee Valley, Tennessee to Georgia and Alabama, Allen (1953), recommended converting forests having fertile soils of limestone origin with northern aspects to shortleaf pine.

Table 3. *Species to Plant, Grouped in Order of Their Average Survival for Each Soil Type-Aspect Class [after Minckler, 1941].*

Dry year, 1939	
Dolomite north slopes:	All species equally good.
Dolomite south slopes:	1. White ash, shortleaf pine, white pine 2. Yellow poplar [1] 3. Black walnut
Limestone north slopes:	All species equally good.
Limestone south slopes:	1. White ash, and black walnut 2. Shortleaf pine [1] 3. Yellow poplar and white pine
Shale north slopes:	1. Black walnut 2. White ash [1] 3. Yellow poplar [1] 4. White pine [1] 5. Shortleaf pine [1]
Shale south slopes:	1. White ash and black walnut 2. Shortleaf pine, yellow poplar, white pine
Wet year, 1938	
Dolomite north slopes:	All species equally good.
Dolomite south slopes:	All species equally good.
Limestone north slopes:	1. White ash, black walnut, yellow poplar, white pine 2. Shortleaf pine
Limestone south slopes:	All species equally good.
Shale north slopes:	1. Black walnut, white ash, yellow poplar 2. White pine [1] 3. Shortleaf pine
Shale south slopes:	1. Black walnut, white ash, yellow poplar 2. White pine [1] 3. Shortleaf pine

[1]Not significantly poorer than the species immediately above or better than the one immediately below.

affected by aspect, planted seedlings grow best on northern slopes. For white pine and yellow-poplar, in a wet year particularly, stiff *B* material makes an inferior planting site. In dry years, sweetgum, white ash, and yellow-poplar are stunted on Southern Appalachian sites with stiff *B* horizons in contrast to more friable subsoils.

Overall, there is not a great difference, as expected, between dolomite and limestone parent materials, and only for pines does limestone appear to be preferable to shale (Minckler, 1943). White pine, however, is safely used with limestone soils within its natural range.

Growth of hardwood plantations in the lower Tennessee Valley is best on deeper top soils. There, too, the effect of low rainfall on mortality is worse on south slopes and on soils with stiff *B* horizons (Minckler, 1943).

Species to plant, grouped in order of their survival for geologic and soil types and aspect class, according to Minckler's (1941) recommendations, are presented in Table 3.

Table 4. *Species Recommended for Planting in the Tennessee Valley under Various Erosion Conditions and Types of Parent Soil Material* [*from Allen, 1953*].

	Parent Soil Material			
Erosion Class	Limestone	Shale	Granite	Gulf Coastal Plain
Gully bottom	BLACK LOCUST LOBLOLLY PINE Shortleaf Pine	YELLOW-POPLAR White Pine Shortleaf Pine	BLACK LOCUST WHITE PINE Yellow-poplar Shortleaf Pine	BLACK LOCUST Loblolly Pine
Gully slope	LOBLOLLY PINE VIRGINIA PINE Shortleaf pine	VIRGINIA PINE	VIRGINIA PINE White pine Shortleaf pine	LOBLOLLY PINE
Severe sheet	VIRGINIA PINE Loblolly pine Shortleaf pine	VIRGINIA PINE Shortleaf pine	WHITE PINE VIRGINIA PINE Shortleaf pine	LOBLOLLY PINE
Moderate sheet	LOBLOLLY PINE SHORTLEAF PINE Black locust	YELLOW-POPLAR White pine Shortleaf pine	WHITE PINE BLACK LOCUST Shortleaf pine	LOBLOLLY PINE Shortleaf pine
Little or none	LOBLOLLY PINE SHORTLEAF PINE Black locust Yellow-poplar	YELLOW-POPLAR WHITE PINE Shortleaf pine	WHITE PINE BLACK LOCUST Yellow-poplar Shortleaf pine	LOBLOLLY PINE Shortleaf pine Yellow-poplar

[1]Capitalized names are those of preferred species.

Table 5. *Planting Chart*[1]. *recommended Species and Site Ratings for Old-Field Planting and Interplanting*2 *in the Appalachian Valley and Adjacent Mountain Regions* [*Numbers refer to directions in the pages which follow* [*from Minckler, 1964*].

Soil profile and erosion	Soil[3] and Vegetative[4] conditions	Topography	Recommended species[5] and mixtures[6] with site ratings[7]: Northerly[8] Slopes	Recommended species[5] and mixtures[6] with site ratings[7]: Southerly[9] Slopes
Accumulated top-soil of 24 inches or more. Homogeneous profile.	Soil friable and permeable throughout Porosity and aeration good to excellent. Drainage10 adequate to rapid. Late stage vegetation usually present within 18 months after abandonment from cultivation. Vegetation usually very dense and tall.	Extreme lower slopes, coves, drained bottoms and sink holes.	BLACK WALNUT, YELLOW POPLAR WHITE ASH' BLACK LOCUST,11	Same as column to left.
No erosion A horizon 12 to 24 inches in depth	A horizon friable, upper half of B horizon friable or only slightly plastic. Porosity and aeration good to excellent. Drainage adequate to rapid. Late stage vegetation usually present within 18 months after abandonment on lower slopes, and 2 years on upper slopes. Vegetation usually tall and dense on lower slopes and coves.	Lower slopes, coves well-drained bottoms, and shallow sink holes	Same as above.	Same as above.
		Upper slopes and broad ridge tops.	YELLOW POPLAR, WHITE ASH, BLACK LOCUST, Black Walnut. Mixtures of SHORTLEAF PINE11 YELLOW POPLAR, WHITE PINE-YELLOW POPLAR.	WHITE PINE12 BLACK LOCUST, yellow poplar, white ash, black walnut, Mixtures of WHITE PINE-SHORTLEAF PINE, WHITE PINE-YELLOW POPLAR, and SHORTLEAF PINE-YELLOW POPLAR.
B horizon present	A horizon friable, B horizon stiff or strongly plastic. Porosity and aeration good in A horizon but poor to fair in B horizon. Drainage adequate. Late stage vegetation usually present within 18 months after abandonment on lower slopes and coves, and 30 months on upper slopes.	Lower slopes, coves, well-drained bottoms, and shallow sink holes	WHITE PINE11 SHORTLEAF PINE, yellow poplar, white ash, black locust, and black walnut, Mixtures of WHITE PINE-SHORTLEAF PINE, white pine-yellow poplar, and shortleaf pine-yellow poplar	WHITE PINE, SHORTLEAF PINE, black locust, black walnut, yellow poplar, white ash. Mixtures of WHITE PINE-SHORTLEAF PINE, white-pine-yellow poplar
		Upper slopes and broad ridge tops.	SHORTLEAF PINE, white pine, white ash. Mixtures of WHITE PINE shortleaf pine, white pine-yellow poplar.	SHORTLEAF PINE, PITCH PINE,13 white pine. Mixture of white pine-shortleaf pine.

No apparent erosion	A horizon friable, upper half of B horizon friable or only slightly plastic, light texture with porous structure and rapid drainage. Late stage vegetation usually present within 24 to 30 months after abandonment. Vegetation usually dense and tall on lower slopes and coves.	Lower slopes and coves	YELLOW POPLAR, WHITE ASH, BLACK LOCUST, black walnut	WHITE ASH, BLACK LOCUST, yellow poplar
		Upper slopes and broad ridge tops.	WHITE PINE, yellow poplar, white ash black locust, black walnut. Mixtures of WHITE PINE-SHORTLEAF PINE, WHITE PINE-YELLOW POPLAR; and SHORTLEAF PINE-YELLOW POPLAR	SHORTLEAF PINE, white pine, black locust, yellow poplar, white ash. Mixtures of white pine-shortleaf pine and white pine-yellow poplar.
A horizon 7 to 12 inches B horizon present	A horizon friable, B horizon stiff or strongly plastic with poor to fair porosity. Drainage adequate. Late stage vegetation usually present within 30 months after abandonment on lower slopes and coves, and 3 years on upper slopes, usually broomsedge rather than blackberry.	Lower slopes and coves.	SHORTLEAF PINE, white pine,yellow poplar. Mixtures of white pine-shortleaf pine, and white pine-yellow poplar.	SHORTLEAF PINE, pitch pine, white pine, mixture of white pine-shortleaf pine
		Upper slopes and ridge tops.	SHORTLEAF PINE, RED CEDAR, pitch pine, white pine.	SHORTLEAF PINE, RED CEDAR, pitch pine.
Moderate erosion. Less than half of top soil lost.	A horizon friable and with a coarse crumb structure. Upper half of B horizon light and friable with high porosity and permeability, drainage adequate to rapid. Late stage vegetation usually present within 30 months after abandonment, usually blackberry or stickweed.	Lower slopes.	Yellow poplar, white ash, black locust, black walnut. Mixtures of White Pine-Shortleaf Pine, white pine-yellow poplar, and shortleaf pine-yellow poplar.	WHITE PINE, SHORTLEAF PINE; black locust, yellow poplar, white ash. Mixtures of WHITE PINE-SHORTLEAF white pine-yellow poplar, and shortleaf pine-yellow poplar
		Upper slopes and broad ridge tops.	WHITE PINE, SHORTLEAF PINE, black locust, yellow poplar. Mixtures of WHITE PINE-SHORTLEAF PINE, white pine-yellow poplar, and shortleaf pine-yellow poplar.	SHORTLEAF PINE, white pine, black locust. Mixture of white pine-shortleaf pine.
A horizon 4 to 7 inches B horizon present	A horizon slightly plastic and sticky. B horizon stiff or plastic with low porosity. Soil texture heavy. Relatively small number of worm and insect holes in soil. Internal drainage slow and permeability poor. Late stage vegetation not present until 4 to 5 years after abandonment, usually broomsedge.	Slopes and ridges	Shortleaf pine, pitch pine, red cedar,[12] white pine.	Shortleaf pine, red cedar, pitch pine

Severe erosion. Over half of top soil lost	A horizon, upper part of B horizon, or AB mixed soil material light and friable to at least 10 inches with high porosity and permeability and rapid internal drainage. Lower part of B horizon only slightly plastic, not stiff. Late stage vegetation usually present within 3 years after abandonment.	Slopes and broad ridge tops.	White pine, shortleaf pine, yellow poplar, black locust, white ash, Mixtures of white pine-shortleaf pine, white pine-yellow-poplar, shortleaf pine-yellow poplar.	Shortleaf pine, pitch pine, red cedar, black locust, white pine. Mixtures of white pine shortleaf pine.
A horizon under 4 inches or composed of A and B mixed material.	A horizon or AB mixed soil plastic. B horizon stiff or plastic with low porosity and permeability. Soil texture heavy, biological activity very poor and internal drainage slow. Late stage vegetation not present until 5 or more years after abandonment, usually broomsedge.	Slopes and ridges.	Red cedar, shortleaf pine, Virginia pine[12] pitch pine.	Red cedar, shortleaf pine, Virginia pine, pitch pine.
Erosion variable. Thin soil layer on bed rock, numerous rock outcrops.	Usually layer of soil 1 to 18 inches deep on limestone bed rock. Soil often AB mixed material. B horizon poorly developed. Soil plastic or stiff with heavy texture and low porosity, excessive surface drainage, dry sites.	Slopes and ridges.	Red cedar, Virginia pine, shortleaf pine[14]	Red cedar, Virginia pine, shortleaf pine

Directions for Use of Minckler's Appalachian Valley Planting Chart

[1]Start at left side of chart and progressively fit prospective planting site into proper compartments until recommended species and mixtures are reached.

[2]Interplanting in undesirable or poorly stocked stands can be done according to the soil-site recommendations in this chart. Small, short-lived trees such as sassafras. persimmon, and sourwood can be interplanted or underplanted with yellow-poplar or white pine and the less dense stands on poorer sites with shortleaf pine. Shortleaf pine, pitch pine, redcedar, black locust, and black walnut should be used only where the planting spot receives nearly full sunlight. Understocked stands of larger longer-lived trees such as shortleaf pine or oak can be reinforced by planting in the openings large enough to allow emergence before overtopping occurs. Plantings which will need release should not be attempted unless the release work can be done.

[3]In the descriptions of soil conditions the terms "friable," "plastic," and "stiff," are frequently used to describe the *consistency* of the soil. Definitions as here used are as follows: *Friable* denotes a loose, crumbly, loamy soil easily permeable to air and water because of the large pore spaces. It cannot be molded into an adhesive ball by pressing in the hands, even when moist. A *plastic* soil is stickier, less permeable to air and water, has a larger proportion of the fine clay particles, and smaller pore spaces. It can be molded into a soft, flexible, adhesive ball when moist, but tends to be loose when dry or moderately dry. It is not in any sense a "hardpan" and offers only moderate resistance to root penetration. A *stiff* soil has a dense, often hard, consistency and is relatively impermeable to air and water. It is usually a clay or silty clay, very adhesive when moist and compact when dry. It is sometimes considered a hardpan or near hardpan and offers considerable resistance to the penetration of roots as well as air and water. Friable, plastic and stiff are relative terms and the soils grade into each other.

There is a correlation between soil types and consistency of the *upper portion* of the *B horizon.* Fullerton and Clarksville soils (derived from dolomite) are mostly plastic or slightly plastic with a tendency to become increasingly friable after abandonment from cultivation. Dewey and Talbot soils (derived from limestone) are usually strongly plastic or stiff. Montevallo and Armuchee soils (derived from shale) are mostly friable or slightly plastic.

There is a definite tendency for sites to improve with length of time since abandonment, especially where the B horizon is not strongly plastic or stiff. This improvement is shown by flocculation of soil particles creating larger pore spaces and increased permeability for water, air, and roots. This is accompanied by increased biological activity and root penetration.

[4]The ecological stage of vegetation gives a rough measure of site fitness. The *pioneer* stage (rag weed, wild carrot, lespedeza, plantain, and poverty grass) persists much longer on the poorer sites. The old-field sites with a stiff B horizon had a preponderance of pioneer stage vegetation. The better sites usually go into blackberry or some king of hardwoods almost immediately. The medium and poor sites gradually pass into broomsedge. This *late* state vegetation of blackberry, sassafras, or broomsedge further improves the site with time. Together with the approximate time since abandonment, both the vegetation stage and density can be usd in conjunction with soil examination in evaluating site.

[5]Because of poor establishment and slow growth the planting of oaks or sweet gum is not recommended. Exotics and planting stock from a distant seed source should be avoided. Fields with a dense cover of mice-infested broomsedge should certainly not be planted to sweetgum or seeded to black walnut or oak. Plantings of black locust, white ash, and yellow poplar, in that order, will also suffer severe rodent damage in densely populated areas. It is probably best not to plant locust in dense broomsedge.

[6]Mixtures should be checkerboard with 9 or 16 trees of one species in a square.

[7]For example:	WHITE PINE	=	site execellent for the species or mixture.
	White pine	=	site satisfactory for the species or mixture.
	White pine	=	site marginal for the species of mixture.

[8]Northwest, north, northeast, and east facing slopes.

[9]West, southwest, south, and southeast facing slopes.

[10]Refers to internal drainage or rapidity with which gravitational (free) water drains from the soild leaving it at field capacity. Inadequate internal drainage is shown by blue-gray or yellowish-gray mottling in the subsoil. Rapid internal drainage is found in soils easily permeable to water, air, and roots. Although relatively scarce, poorly drained areas are not good planting sites.

[11]Black locust, white pine, and shortleaf pine are relatively intolerant to competition from tall dense vegetation on the planting site. Shortleaf pine is the most intolerant and should not be planted on areas with dense briars, weeds, or brush. Locust and white pine are more tolerant but the most densely vegetated areas should be avoided. Such sites are usually suitable for yellow-poplar.

[12]Regardless of other site conditions, white pine and yellow-poplar should not be planted on southerly slopes with a steepness of about 30 percent or more. Substitute shortleaf pine or pitch pine.

[13]Pitch pine, redcedar, or Virginia pine should be substituted for shortleaf pine above the safe altitude for shortleaf pine; about 2,500 feet in eastern Tennessee, western North Carolina, and southwestern Virginia. Pitch pine should be used on the better shortleaf pine sites and redcedar or Virginia pine on the poorer sites, as indicated in the chart.

[14]Shortleaf pine will probably not reproduce well on limestone soils; for example, Dewey or Talbot. If planted on these soils it will grow, however, and is satisfactory as a pioneer forest crop.

Allen's (1953) analysis of a half-century of reforestation in the Tennessee Valley resulted in the planting recommendations of Table 4. Planting situations outlined by Minckler (1946a) (Table 5), are modified as follow:

(1) Pasture rehabilitation, both overgrazed and eroded. Plant black locust at 6x6- or 8x8-foot spacing. Exclude cattle until foliage is above their reach and sod cover is complete. This initial species should not be expected to yield merchantable wood other than for fence posts. Steep south slopes should be avoided, but on moderately eroded sites, it responds well to phosphorus fertilization at time of planting (Allen, 1953). As a result, early rapid growth combats the locust borer when it is on deep, moist, well-drained soils on northern or protected sites.

(2) Badly eroded shale and sandstone areas. Plant Virginia, shortleaf, or pitch pines. Virginia pine, planted at 5x5-foot spacing, seems best on most eroded areas. Pitch pine should be used at elevations above 2500 feet.

(3) Abandoned old-fields or pastures, not eroded. Plant white, shortleaf, Virginia and pitch pines; or eastern redcedar. Yellow-poplar can be used on moist sites. Redcedar should not be planted within ¼ mile of apple orchards due to cedar-apple rust injury to fruit trees.

(4) Limestone outcrops. Plant eastern redcedar here for a potential post crop, even on shallow soils.

(5) Poor hardwood stands. Plant shortleaf pine on the poorest

sites, white pine on the better sites facing north and east, pitch pine on driest sites above 2500 feet elevation. White pine has a greater tolerance to shade than either pitch or shortleaf pines and therefore is recommended for the less sunny aspects. It should not be planted on steep south slopes. Moderate erosion is allowable, but the **A** horizon should be at least 5 inches deep so that the topsoil is loose and mellow when worked. Drainage should be fair to good. Avoid tall dense brush, but light, open cover is beneficial. Apparently sassafras serves to improve worn-out soils by early development of ground cover which encourages an accumulation of organic matter in the upper mineral soil layer. Yellow-poplar does well when underplanted in even the denser stands of sassafras, but white pine, while making a good start, requires liberation (Minckler, 1941).

Deficiency symptoms have been worked out for basswood, indicating the species is rather demanding of the essential nutrients for plant growth. It should not be encouraged on soils low in bases and in phosphorus (Ashby, 1959; Ashby and Mika, 1959).

Spoil Banks - Strip mined areas in the more northern reaches of the southern upland hardwood forests are afforested readily with black locust. In addition to initial vigor, crowns close and litter is deposited rapidly, and soil nitrogen is increased. Because severe borer damage may occur on acidic soils—less than pH 6, European black alder is a possible substitute (Lowry, Brokaw, & Breeding, 1962).Planting is generally superior to direct seeding on such sites. After the locust or alder plantation is established, black walnut, yellow-poplar, silver maple, and osage orange have been underplanted with some success. Adding nitrogen and phosphorus enhances growth of these species under these conditions (Ashby and Baker, 1968). Where subsequent plantings are anticipated, a prostrate mutant of black locust—reported by Kriebel (1960)—which would not overtop other species is desirable.

Underplanting - Underplanting of yellow-poplar, northern red oak, and green ash in a recently thinned loblolly pine stand on a poor soil in the South Carolina Piedmont was successful, but growth is too slow for profitable practice (Wells, 1961, 1964). Growth was directly related to nitrogen in foliage,[4] indicating that fertilization may be desirable. However, in the reported study, nitrogen and phosphorus were probably taken up by overstory pines or leached from the root zone. Slowly soluble fertilizers hold promise for such plantings.

Gibberellin - Although sweetgum seedlings in one instance responded to applications to stems of 1 percent solutions of gibberellin in lanolin, on other occasions this and other species failed to have growth influenced by the fungus abstract (Nelson, 1957a).

Northern Zone - Soils on which reforestation is appropos in the northern zone of the Southern Appalachian Mountains are those derived from sandstones, shales, and cherty limestone with slopes of

[4] 1.08% nitrogen in yellow-poplar leaves is the critical level.

more than 30 percent. On slopes greater than 60 percent, all soils belong in forests.

Yellow-poplar, black locust, and white ash are suitable for north and east slopes, lower to middle south and west slopes, coves, well-drained bottoms and sink holes. The surface soil should be at least 6 feet deep. Subsoils which are loose and friable when worked to a depth of 12 inches and which do not become hard and cloddy are good sites. Favorable drainage is a requisite.

Moderate to heavy cover may be beneficial to yellow-poplar and white ash; while light, open cover benefits black locust. Briers and brush indicate a good black locust site, but sod and broomsedge where briers and brush are absent should be avoided. Black locust is acceptable for deep gully control provided the soils are light-textured or there is an accumulation of debris in gully bottoms.

Black walnut is best suited for lower slopes, coves, well-drained bottoms and sink holes where erosion has not taken place. Surface soils over 8 inches deep with at least 16 inches of loose, friable subsoil with good drainage are essential. This species should not be planted on broomsedge sites without first disking or plowing. Light to moderate brush cover is desirable for protection from animals and desiccation (Minckler, 1943).

Hybrid Poplar - Hybrid poplars, first introduced in the United States several decades ago in the Northeast, show promise in the South on topographic situations ranging from the mountains to the Coastal Plain. Recommended hybrids represent the fruition of efforts to cross-breed most of the poplar species of the world but, unfortunately, many of the strain identifications are lost. Reproduction is readily obtained from cuttings.

In mountain coves, hybrids of Strathglass, Androscoggin, and Geneva clones outgrow the fastest growing native species, including white pine, yellow-poplar, and northern red oak. With cultural treatment, including clean cultivation of planting sites, the Androscoggin clone grows at a height of 80 feet and 10 inches dbh in 13 years (Doolittle, 1953).

A Tennessee Valley stand in 5 years had almost 100 cubic feet per acre, a basal area of 80 square feet, and heights of 25 feet. The 3400 stems per acre were then thinned to 800 with a basal area of 20 square feet. Another planting, at 12x12-foot spacing, averaged 11 inches dbh in 10 years (Blow, 1948) (Fig. 5).

Sod should be eliminated from 2-foot strips on each side of the planting, turning the sod into the soil to improve its fertility and physical properties (Shreiner, 1955). Weeding will probably be required for 2 years, after which roots are uninhibited by grass, spread out below grass roots to function at lower depths, or much more abundant.

Intermediate Management

Thinning

In thinning from above, trees left should be of medium vigor or

Figure 5. *Hybrid poplar 10 years old in the Tennessee Valley [from Blow, 1948].*

better, but even then, subsequent growth may not be as good as in thinning from below. Within a crown class, response to release generally increases with increasing vigor.

White oak and sugar maple are very tolerant. As such they readily recover from suppression but, unfortunately, become spindly and easily bent as they grow into holes in the canopy. Where trees of these species are dominant and of good vigor, one thinning or improvement cutting is sufficient to provide adequate release for the balance of the rotation. In pole-size sugar maple stands, thinning should be from below to improve crop trees or to salvage suppressed trees likely to die. Thinning of poles from above is acceptable if immediate financial returns are desired, provided the next cut can be made from trees now in the codominant and intermediate classes. Yellow-poplar, in contrast to most hardwoods, is sensitive to suppression, but a vigorous dominant dones not require release. Response to release for these three species increases with their increasing order of tolerance: yellow-poplar, sugar maple, white oak. Species having similar responses are, according to Downs (1946),

yellow-poplar: black locust, black cherry, butternut.

white oak: American ash, hickories, oaks, birches, cucumber tree, basswood, white pine, black walnut, elm.

sugar maple: red maple, beech, hemlock.

Sugar maple precommercial thinning is recommended by Downs (1946). When sapling stands are thinned, diameter growth rate over that of unthinned trees is doubled in 7 years.

Weeding

Weeding is at least theoretically beneficial, shown by the fact that red maple forests might transpire more than twice as much water as white pine stands with trees of the same size (Zahner, 1955). Removal of the maple therefore provides considerable additional moisture for more desirable hardwoods and conifers. Presumably other deciduous weed trees behave similarly to red maple. Diameter and, perhaps, height growth of residuals, particularly in the lower crown classes, are stimulated by weeding. Mortality is reduced and suppression prevented as the crown class of released trees is raised. Intensive cleaning also increases browse production (Della-Blanca, 1969). Within species, trees with lower crown classes and highest vigor respond most to release (Downs, 1942) (Table 6).

Table 6. *Weedings Recommended for Various Crown Class-Vigor Class Combinations* [*after Downs, 1946*].

Crown Class	Vigor Class		
	Good	Medium	Poor
Dominant	1	Not needed	Not recommended
Codominant	1	1	Not recommended
Intermediate	1-2	2	Not recommended
Overtopped	2	Not recommended	Not recommended

Light treatments are frequently as good as heavy ones if, by this, is meant the distance from crop trees to which competition is removed. Cutting back crowns of all vegetation which reaches ⅓ up the crown of the crop tree for a distance of 1½ feet from margins of crop trees, and removing all vegetation taller than crop trees for 3 feet from the vertical projection of crop tree crown margins provides no less stimulus than would removal to 3-foot and 6-foot radii. Only for sugar maple has the heavier weeding been found more effective. Low cutting, in which understory weed trees are removed, is ineffective. Among the broadleaf species to incourage, under present market conditions, are yellow-poplar, white oak, sweetgum, and red oak. Control measures should be employed on hickories, red maple, beech, sourwood, and dogwood if not locally marketable. Only for exceptional upland sites, such as an area farmed briefly and on which erosion is absent, are deciduous trees to be encouraged in the Southern Piedmont (Downs, 1946) (Table 7.)

Table 7. *Vegetative Competition to Crop Trees and Recommended Practice* [*after Downs, 1942*].

Stand Condition	Practice
1. Trees same size or taller than the crop tree.	1. Trim branches which are within 3 feet of lines drawn vertically up from the outer edge of the crown of the crop tree. Cut or girdle trees whose stems occur on the border of or within this area, or when branches within this area cannot be reached.
2. Trees shorter than crop tree but with tips reaching one-third or more up the crown of the crop tree.	2. Cut or trim trees the crowns of which are within 1½ feet of the edge of the crown of the crop tree.
3. Trees or shrubs with tips reaching less than one-third of the way up the crown of the crop tree.	3. Cut none, except as required for free movement of workers.

Choice of crop trees among upland hardwoods is important. Stocky strong trees respond best to release. Trees not to select generally are (1) tall spindly stems, (2) those with dead branches in the upper halves of their crowns, and (3) trees with crown length: total height ratio less than 1/5. Selected trees should be at least three-fourths as tall as the average crown level, as the criteria are difficult to judge for smaller trees. Forked and crooked trees are removed in all cutting operations.

Degrees of weeding suggested are: (1) when growth rates of weed trees are greater than for crop trees, release heavy; (2) when heights of weed trees are greater than crop trees, release heavy; (3) when good vigor is shown for crop trees, as when a desired species is more or less uniformly overtopped by weed trees such as fire cherry or sugar maple, overtopping has not been of long duration and one weeding is probably sufficient; (4) when medium vigor indicates suppression has begun and weed trees are taller than crop trees, one to two weedings, depending on differences in height, are needed; and (5) trees of poor vigor, where overtopping has obviously been of long duration and great differences occur between crop and weed-tree heights, release only when the overstory is worthless and where prepared to make several weed cuttings.

Deciding what to weed is difficult when a mixture of crown classes, vigor classes, and species occur. Medium vigor, overtopped trees are poor risks, as are all poor vigor trees, and should not be freed of competition. Vigorous dominant stems need no release when weed trees have equal or lesser growth rate and are not crowded by fast-growing weed trees (Table 8).

Table 8. *Crown Classes of Various Species for Which Weeding is Recommended* [*from Downs, 1942*].

	Dominant	Codominant	Intermediate	Overtopped
Sugar maple	X	X	X	X
White oak		X	X	X
Yellow poplar			X	X
Cucumbertree			X	X
Eastern red oak			X	X

Effects of stand improvement 5 and 10 years after treatment are recorded by Buell (1943) for forests from West Virginia to Georgia. Without regard to season of treatment, only 2 and 4 percent of released crop trees were over-topped 5 and 10 years, respectively, after girdling their neighbors. Sprouts of trees cut threatened 8 percent of the released crop trees after 5 years and 18 percent after 10 years, making a second release cutting desirable. Although less than one-half of the vines threatened crop trees at the end of 5 years, retreatment will be required for their control. Height growth of residuals averaged about 40 percent better 5 years after release than before treatment, while suppressed trees remaining sustained their growth. Diameter growth increased over 50 percent following the improvement cut in contrast to a 10 percent decrease among untreated stems.

Ericaceous Shrubs - Ericaceous shrubs, such as mountain laurel, rhododendron, and wild azalea must be controlled for efficient forest management in the region as thickets of shrubs preclude natural regeneration and prevent establishment of plantations. Both mountain laurel and rhododendron grow about 6 feet in height in their first 10 years, about 4 feet the next five, and ½ foot per year thereafter until age 20. Growth in height seldom exceeds 20 feet. Ericaceous shrubs have no commercial value: once pipe bowls were made from their burls and rustic furniture from their stems, but to hold the land together and to please the eye of man make up the present usefulness of Ericaceous jungles. These areas generally are best converted to white pine through intensive practices.

Good rhododendron sprout control has been obtained by spraying with 2,4,5-T in fuel oil. Concentrations of 8 pounds of acid equivalent per 100 gallons of mixture appears adequate (Sluder, 1961).

Table 9. *Index Numbers for Computing Epicormic Branching [from Jemison and Schumacher, 1948].*

For Step 1

Volume cut per acre M bd. ft.	Original stand volume per acre, M bd. ft.								
	4	5	6	7	8	9	10	11	12
0	4.79	4.86	4.93	5.01	5.08	5.15	5.22	5.29	5.36
1	4.82	4.89	4.96	5.04	5.11	5.18	5.25	5.32	5.39
2	4.84	4.91	4.98	5.06	5.13	5.20	5.27	5.34	5.41
3	4.86	4.93	5.01	5.08	5.15	5.22	5.29	5.36	5.43
4		4.95	5.03	5.10	5.17	5.24	5.31	5.38	5.45
5			5.05	5.12	5.19	5.26	5.33	5.40	5.48
6				5.15	5.22	5.29	5.36	5.43	5.51
7					5.24	5.31	5.38	5.45	5.53
8						5.33	5.40	5.47	5.55
9							5.43	5.50	5.58

For Step 2

Tree height and log position	Species					
	Yellow poplar	Northern red oak	Chestnut oak	Hickory	Red Maple	Sweet birch-white ash-basswood
1-log trees						
butt log....	0.34	0.09	0.42	0.17	-0.35	0.46
2-log trees						
butt log....	0.09	-0.16	0.17	-0.08	-0.60	0.22
top log	0.19	-0.06	0.27	0.02	-0.50	0.31
3-log trees						
butt log....	-0.20	-0.44	-0.12	-0.37	-0.88	-0.07
2nd log....	0.20	-0.05	0.28	0.02	-0.49	0.32
top log ...	0.28	0.03	0.36	0.11	0.40	0.41

Epicormic Branching

Epicormic branching is a serious degrader of lumber quality for Southern Apalachian hardwoods, especially upon thinning old-growth stands with trees of sawtimber size—over 12 inches dbh. The amount of sprouting on various logs depends upon their position within the trunk and clear height, being greatest for top logs and least for butt logs. It is also greatest where cutting is most severe and stand volume drastically reduced.

In a study of trunk sprouting of old-growth hardwoods in a dense stand, almost half of the logs had no sprouts, ¼ had 1 or 2, ¼ had 3 to 9, and only 5 percent had 10 or more. After partial cutting, almost one-half of the residual logs had more branches a few years later than they had before cutting. Only 3 or 4 branches on a grade 2 top log are necessary to reduce that log's quality to grade 3. Profile branching on trees of lower crown classes indicates that high-quality even-aged stands of white oak cannot be grown in competition with the faster growing black oaks (Krajicek, 1959).

In descending order, the amount of bole sprouting in closed stands, for various species, is hickories, chestnut oak, yellow-poplar, basswood-white ash-black birch group, red maple, and northern red oak. After opening stands to let light strike the trunks of tress, the descending order is ash-basswood, white ash-black birch, chestnut oak, yellow-poplar, hickory, northern red oak and red maple (Jemison and Schumacher, 1948). The probable number of branches for any combination of factors in second-growth hardwoods can be calculated from Table 9 and Figure 6.

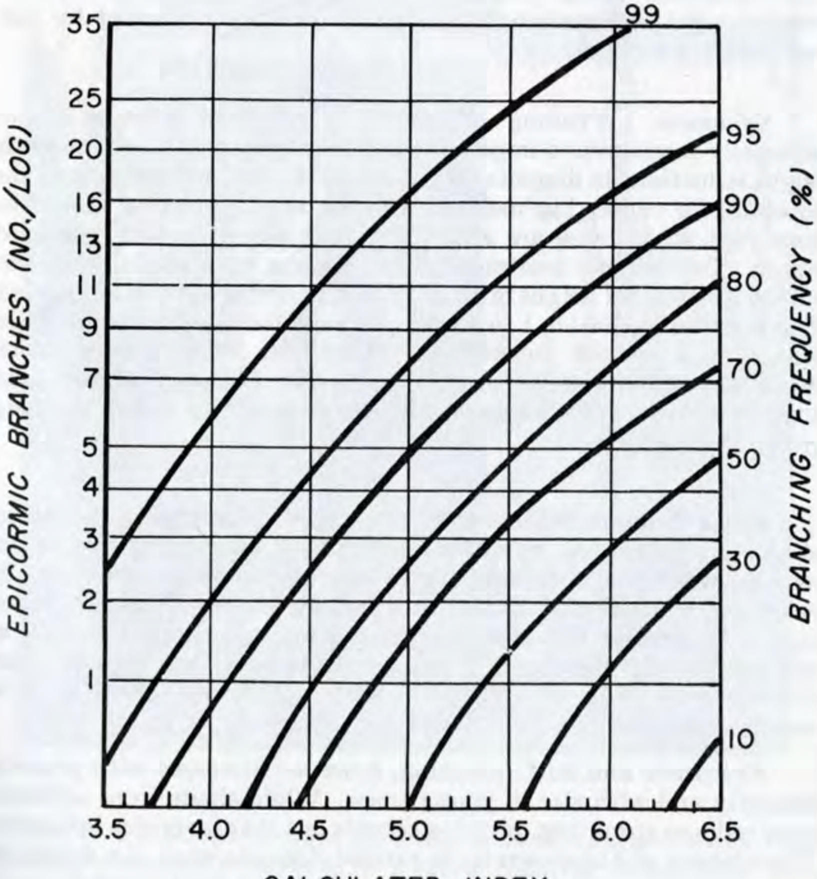

Figure 6. *Relation of frequency of epicormic branches per log to the calculated index, based on original stand volume, volume cut, species, tree height, and log position [from Jemison and Schumacher, 1948].*

For example, it is desired to determine the number of epicormic branches on the top log of a 3-log yellow-poplar in a stand in which 4 MBM are cut from a forest averaging 8 MBM before harvest. Enter Step 1 from the table in the row representing 4 MBM and the column for 8 MBM. An index number of 5.17 is obtained. Now, enter Step 2 and note that the index for the top log of a 3-log yellow-poplar is 0.28. Add 5.17 to 0.28. To total, 5.45, is entered is the Figure 9 under indexes total. From this we find that 35 percent will have no branches 7 years after cutting, 49 percent will have 1 branch, 70 percent will have 3 or less, and 94 percent will have 11 or less.

Pruning

Conventional pruning may be shortly replaced with chemi-pruning, using 2,4-D, 2,4,5-T, and other herbicide sprays. MacConnell and Kenerson (1964) found summer treatment for oak and maple preferred.

Sycamore - Pruning of sycamore in dense stands is not especially conducive to improving either diameter or height growth. Slight reductions in diameter growth may result, but quality and the potential for veneer log markets are enhanced. Pruning should be done first when trees are about 10 years of age in widely spaced stands. Two or more treatments 3 and 8 years later, raising the clear bole in 3 steps to a height of 18 or 26 feet (1 or 1½ logs) is suggested. Pruning wounds heal in 1 to 2 years with neither decay nor epicormic branching a serious consequence. (Doolittle, 1956; Sluder, 1959) While the difference in clear bole height between pruned and unpruned trees will disappear with time, knot-free wood is being grown in the interim.

Black Walnut - Black walnut pruning which removes 75 percent of the live crown has no adverse effect, but 50 percent live crown removal was found optimum for subsequent growth of trees about 20 years old, 5 inches dbh, 25 feet tall, and with crowns closed. In one report, 75 percent live crown pruning stimulated height growth at the statistically significant 1 percent level over non-treated trees (Clark, 1955) (Fig. 7). Wounds heal rapidly and there is little resultant dacay.

Epicormic and butt sprouting, however, increases with pruning intensity and with size of young trees. While shade from adjacent trees reduces sprouting, pruning cancels out that favorable influence. The amount of live crown to be pruned depends upon the degree of both epicormic and butt sprouting which can be tolerated.

Watershed Management [Southern Appalachians]

Although some mountain forests are poor for production of wood products, their intensive management for maintaining a steady and abundant flow of pure, clear water is warranted. Thus,

Figure 7. *Upland hardwoods. Callus growth is rapid and many small pruning wounds are closed after 2 years. Note the sprout just below the pruning wound [from Clark, 1955].* (USFS Photo).

influences of cutting practices, grazing, and logging road construction upon the soil are both silviculturally and hydrologically significant. Hursh and Hoover (1941) found soil profile characteristics associated with porosity to be most responsible for hydrologic conditions, and removal of litter and cultivation have long been observed to greatly increase runoff and thereby reduce water available for storage in the soil. Siegworth and Olson (1957) reported on infiltration changes resulting from forest protection and management practices. Where forests of the Southern Appalachians were protected from fire and grazing for a 9-year period, infiltration rates were many times better than where not protected. Vegetation types influence the rate of infiltration of water into the surface soil. Thus, the effect of various stages in plant succession--from abandoned fields, through Virginia pine, to oak-hickory forests--upon the infiltration capacity of a gravelly loam soil is noteworthy. No runoff occurred for the hardwood forests, regardless of rainfall intensity up to a rate of 3 inches per hour. Virginia pine sites were nearly as favorable for water absorption during storms of very high intensity, but as much as 16 percent of rainfall was lost as runoff. One-half of the precipitation on old-fields ran off with storms as light as 1½ inches per hour (Alderfer and Bramble, 1942). Runoff during intense storms is apt to occur because rainfall exceeds the volume of available pore space in the surace soil. Ocasionally, the number of inches of rain may exceed the depth of the surface soil of ridges and higher slopes.

Hydrology

"One foot of soil, eroded from one square mile of watershed, means one million cubic yards of sediment moving to the streams and ditches and reservoirs below" (Wilm, 1947). This rule of thumb forcefully brings to attention the seriousness of the erosion situation when it is considered that much farmed and grazed mountain land has lost a foot of surface soil, and accelerated erosion continues on skid trails, logging roads, log landings, and overcut areas. Hursh (1946) discusses in detail the following abbreviated facts foresters should know about water production:

(1)**Water discharge** is the product of the cross-sectional front of a stream and the rate at which that front passes a point. Thus, a stream 20 feet wide and averaging 6 inches deep has a "front" of 10 square feet in cross section. A twig carried with the current at an average of 2 feet per second, indicates the velocity. Water discharge = 10 square feet x 2 feet per second, or 20 cubic feet per second (cfs).

(2) **Stream flow rate** is the water discharge divided by the area of the watershed. Hence, if from a topographic map a stream is ascertained to drain 10 square miles of watershed, it is recorded in cubic feet per second per square mile (csm). The stream flow rate = 20 cubic feet per second÷10 square miles = 2 (csm).

(3) Now, water flowing at a rate of 1 cfs passes 646,317 gallons per day, or the equivalent of 2 acre feet, at any point along a stream. To produce this amount of water, the soil must be in condition to store it until released at a rate of 0.7 gallon per minute per acre. Since 1 acre-foot of water amounts to 323,158 gallons (43,560 cubic feet), to add 1 foot of water to a lake 1 acre in area requires a flow of water at the rate of 0.7 gallon per min-

ute from a 1-acre watershed for 115 weeks or, more practically, 1.15 week from a 100-acre watershed.

(4) In the Southern Appalachian Mountains, summer months with individual rains not exceeding ½ inch are not uncommon. If such a month has just passed and no rain of any degree has occurred for 3 days, then 2 csm is a high yield, 1 csm is a good yield, ½ csm is an average yield, and 0.2 csm approaches drought conditions.

(5) The **water cycle** is $Q = P - (I + E + T + X) \pm S$

Where	Q	=	water flow in a channel
	P	=	precipitation (generally a constant)
	I	=	interception
	E	=	evaporation
	T	=	transpiration
	X	=	runoff and deep seepage
and	S	=	water storage

Hence, estimated circulating water capital for a watershed can be periodically calculated and used as a water invoice on a ledger sheet.

P, E, X, and S are measured and T is estimated. As watershed management becomes integrated with silviculture, such invoices will be necessary (see Kittredge, 1948; and Forbes, 1955). If Q is measured or known, S may be solved. Estimates for T are from the equation:

$$T = 0.048t - 3.38 \text{ (March to July)}$$

$$T = 0.087t - 3.72 \text{ (August to November)}$$

where t = average monthy temperature in F degrees. T is, of course, 0 in the dormant season.

A quantitiative relationship between rainfall, runoff, and moisture storage opportunity (the ratio of available storage to rainfall) in the upper 6 inches of soil for an old-field watershed in north Mississippi enables runoff predictions and is especially inches fall 2/8 = 25%), predicted runoff is about 3 percent of rainfall accurate for winter storms when storage capacity is known. Thus, if 2 inches of water can be stored in a particular soil and a rain of 8 (SFES, 1959) Fig. 8).

Water Stored in Trees - Internal storage of water in the wood, bark, and leaves of trees may be appreciable, particularly for hydrologically shallow soils (Satterlund, 1959). For Yellow birch, storage capacity on a good site with old trees could amount to ½ inch, and for old beech stems on good sites ¼ inch. The difference in moisture content of a tree between the spring and early summer high and the autumnal low has amounted to 40 percent. Vegetatively stored water volume may be assessed from water yield tables for various species, determined by the formula:

$$D = \frac{12. (M1 - M2) \, Sg \, .Y}{43{,}560}$$

where	d	=	inches depth of water over a watershed,
	M1	=	the maximum moisture content, in percent, oven-dry weight of wood
	M2	=	the minimum moisture content, in percent, oven-dry weight of wood,
	Sg	=	the mean specific gravity of the wood,
and	Y	=	total wood volume of the stand, in cubic feet per acre, from yield tables.

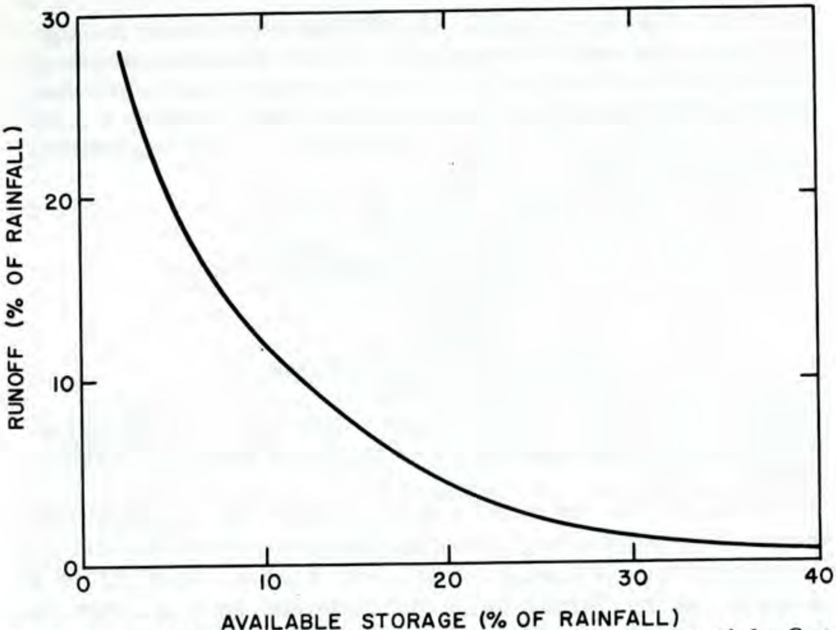

Figure 8. *Relation of runoff to prestorm storage capacity of the O- to 6-inch soil layer. The relative rate of infiltration is shown if the vertical axis is read as 1, 2, and 3 inches of rainfall per hour and the horizontal as infiltration time in minutes* [*after SEFES, 1959*].

Since few yield or volume tables are constructed to give total volume of both stem and branchwood, the volumes given must be adjusted as follows: for pines, add about 14 percent of total volume, in other conifers about 12 percent, and in hardwoods 21 percent. Where hardwood yield tables give volumes to a 5-inch top dib, a proportion of 25 percent is used.

Road and Trail Erosion Control

A protection forest is defined as an area wholly or partly covered with woody growth and managed primarily for its beneficial effects on water or soil movement rather than for wood production (Kittredge, 1948). On such forests, especially, erosion as well as storm runoff must be held to a minimum. Proper skidding methods and skid road and trail layout and maintenance are essential for protection against unnecessary water quality and quantity losses. Forest roads should not be built where there is evidence of badly faulted rock, shattered rock, land slides, heavy clay soil, and other evidences of xeric sites and unstable slopes. Direct ground skidding of logs is common in the region. Frequently, the dragged logs create channels which concentrate runoff from the road surface to which logs are skidded into streams that develop considerable erosive force. Hoover (1945) recorded an operation in which 3000 cubic feet of sediment were trapped from a mile of skid road with a 30 percent grade during a 3-month summer period. During that period, turbidity of the stream into which the sediments flowed averaged 94 ppm with a maximum of 3500 ppm, while unlogged watersheds had an average turbidity of 4ppm and of 80ppm. Good logging techniques can hold average turbidity to 5ppm, well below the drinking water maximum turbidity standards of 10ppm (Lieberman and Hoover, 1948; Black and Clark, n.d.; Hoover, 1952).

Proper layouts of skid trails are as convenient to design as those conducive to erosion. They involve (1) skidding up hill to parallel logging roads so that water draining from the logging road is dispersed as it flows downward in the host of trails, each originating from a different point, (2) turning water out of skid trails in which numerous hauls have been made, using small waterbars, (3) maintaining the waterbars of skid trails daily—in the long run, this reduces logging costs, (4) laying corduroy of slash logs across trails, and (5) avoiding gradients exceeding 20 percent.

Log skidding in mountainous watersheds should be tree-length, up-hill, and with power equipment. The butt-end of the tree is skidded to ridges between small draws, not across or along streams. Skidding uphill provides a palmate pattern with the palm at the top and the fingers below. Water collecting at the palm—the loading point—is despersed down the fingers. With the palm down, water collects, to cause a build-up for further erosion. Adjacent to stream banks where erosion control and recreational values are important, cutting should be in discontinuous strips, and logs should be skidded away from streams.

A rule of thumb for the minimum safe distance a logging road should be from a stream is outline by Trimble and Sartz (1957). Where some sediment is acceptable, starting with a strip 25 feet wide on level land, the width may be increased 2 feet for each 1 percent increase in slope between road and stream. For watersheds where no appreciable sediment is permitted, safe logging may start 50 feet from a stream and increase 4 feet for each 1 percent increase in slope (Table 10). Culvert spacing, road surface conditions, steepness of road grade, amount of sediment trapped in small coves, and amount and arrangement of logging slash and fallen tree debris (whether impeding or dispersing water) are factors which modify the minimum distance between roads and streams.

In logging roads through the forest for truck use, grades should be below 8 percent, except for short distances where the limit is 15 percent. Steeper grades are all right for use a single day or so, if promptly "put to sleep." Long, steady grades permit buildup of drainage water and increase erosion potential unless adequately provided with waterbars placed at angles to permit self-cleaning of soil and debris. After roads and trails are no longer in use, they are promptly "put to sleep," at which time the frequency of waterbars increases with road grade (Table 11). Waterbars include wooden troughs and shallow hand-dug trenches mounded so as to conduct water to the lower side. Grades less than 5 percent, of unlimited length, should have drains no further apart than 500 feet. Medium grades—6 to 10 percent—should not exceed 1000 feet distance and have surface drains at least every 300 feet. Maximum length for grades between 11 and 15 percent is 800 feet and distance between drains 200 feet. Spacing for skid trail water bars is determined by dividing the road grade into 1000: thus, the bars are every 100 feet where the grade is 10 percent. Long, relatively level sections with grades less than 3 percent, and consequently poorly drained, should

Table 10. *Minimum Distances Between Logging Roads and Streams Where [1] Some Sediment Is Permissive and [2] No Sediment Is Acceptable [after Haussman, 1960].*

Slope of land between road and stream	Widths of filtration strip	
PERCENT	FEET	
	(1)	(2)
0	25	50
10	45	90
20	65	130
30	85	170
40	105	210
50	125	250
60	145	290
70	165	330

Table 11. *Recommended Distances Between Waterbars on Skidroads Which Have Been "Put to Sleep" [from Haussman, 1960].*

Grade of road	Distance Between water bars
PERCENT	FEET
2	250
5	135
10	80
15	60
20	45
25	40
30	35
40	30

be avoided. When sharp curves of 50 feet or less radius are necessary, as on switchbacks, the grade must be reduced to less than the approach grade and should never exceed 10 percent. Stream beds are never used for roads (Hausmann, 1960; Jones, 1955; Weitzman and Trimble, 1952, 1955).

Haupt (1959) discusses skidroad and slope characteristics affecting sediment movement. For certain western conditions of steeply sloping granitic soils, not unlike many southern situations, the distance sediment moves downslope depends upon (1) slope obstruction index, a calculated value based upon ground cover, debris, and standing trees; (2) the distance between cross ditches, or waterbars; (3) length of the embankment on the lower slope of the road; and (4) road gradient. These characteristics are incorporated into an equation which promises to be valuable in determining the safe width of buffer strips necessary to protect lower roads or stream channels from sediment damage. For southern conditions, additional factors not important in the West, including intensity of storms, are important.

Roads "Put to Sleep" - When skid trails and logging roads are "put to sleep" following active use, seeding grass and installing waterbars are necessary. In addition to controlling erosion, deer, rabbits, and game birds are benefited by the forage and its accompanyng insect life.

A recommended practice is to:

(1) prepare the site with a chain-type spike hook harrow attached to a crawler tractor,
(2) apply ½ ton per acre of complete fertilizer, such as a 2-12-12 formulation,
(3) apply 1 ton per acre of limestone to supply adequate calcium and to raise the pH, and
(4) plant 20 pounds per acre of seed mixture of high quality for wildlife forage, such as shade fescue, hard fescue, Kentucky bluegrass, and meadow fescue (Sealy, 1960).

Another recommendation, following site preparation, is to
(1) apply 2 tons per acre of limestone,
(2) fertilize with 1 ton per acre 2-12-12 plus 1 ton per acre of 20 percent superphosphate, and
(3) plant orchard grass and Ladino clover in the spring at rates of 13 and 3 pounds per acre, respectively Morris, 1945) (Fig. 9). Lespedeza, rye, and other cover crops are also employed.[5]

The Public Road Problem - Frank, in 1941, spoke prophetically in calling headwater highways "a new forest menace." Since his writing, the situation has worsened. Recently the writer fished a stream in north Georgia with an excessive turbidity several miles below where a state road—not a super highway—crosses the creek.

[5]Other techniques, including the use of vegetation and structures, for gully control are given in Jepson (1939).

Figure 9. *Grass and clover cover on a skid trail [from Morriss, 1954].* (USFS Photo).

On the lower side of every rock outcrop, sand had accumulated and silt remained in suspension. One may walk up a stream during a storm to find the source of turbidity usually relatively small sore spots.

Excessive drainage from slopes on the upper side of road cuts may result in abnormally dry conditions for tree growth. Also, if water is concentrated in road drains, slopes on the lower sides of highways may dry out to the degree that strips of timber die. Forest margins, accordingly, have receded up to 150 feet on upper slopes and 50 feet on lower slopes because of the inability of the soils to store sufficient water (Frank, 1941). There is some difference in opinion as to whether conifers or deciduous trees are best adapted to the xerophytic conditions artificially created along mountain roadbanks. Although honeysuckle and kudzu continue to be used for roadbank stabilization, it is now clear that these vines do not control erosion; they only hide it.

Factors Affecting Waterflow

Silvicultural practices of controlling stand density and species composition have an influence on interception of rainfall, transpiration, infiltration, and percolation. Heavy thinning decreases interception and transpiration losses and, to a lesser degree, increases evaporation losses from the surface of the forest floor. Infiltration and percolation are dependent upon the organic component of the surface soil and the unincorporated leaf litter as well.

Recent findings suggest that transpiration of moisture from grass may be as important as water loss from tree foliage in the hydrologic cycle. The amount passed to the atmosphere by both types of vegetation makes a sizeable contribution to space in the soil available to receive and store precipitation for the alleviation of damaging storm flows. For those grasses which are more shallow-rooted than pine, if there are any, water yield on sites so sodded may be greater than that of conifer sites (SEFES).

Leaf Litter - Hardwood litter catches and holds water, and from it is evaporated 1/20 of the first inch of rain. At field capacity, moisture in hardwood litter averages 135 percent of oven-dry weight. After soaking rains, the average is 175 percent: 10 days later, it is only 41 percent, 25 days later it is 25 percent, and after that it is relatively stable. The upper 4 inches of bare soil is 20 percent drier than litter-covered earth. Water management of hardwood forests in mountainous regions includes maintenance of accumulated litter on the ground by regulating the cut and through species assignment.

Leaf litter supply can be estimated from tree diameter or by branch diameter. Although leaf weight and leaf area vary in successive years, the number of leaves is relatively constant for diameter classes. Site quality has little effect on the number of leaves, except as better sites produce larger trees. In a sample acre of mixed oak, with basal area of 60 square feet, foliage area ranged from 4.3 to 5.2 acres and oven-dry weight from 1.3 to 1.7 tons per acre (Rothacher, Blow, and Potts, 1954) (Fig. 10).

Litter of a poor oak site with a thin mor humus layer is about 3000 pounds per acre for the *L* layer, 6000 pounds for the *F* layer, and 18,000 pounds for the *H* layer of unincorporated organic matter (Carmean, 1959). From 2 to 12 tons of litter accumulates on each acre, depending on fire history, cutting practices, and stand composition: 5 tons is a favorable amount. In a mixed oak stand where the annual leaf fall equals 1.3 tons per acre, total litter reaches a peak of more than 5 tons per acre in December and decreases to a low in August of 4.2 tons. A 2-inch layer of undecomposed pine needle litter weighing over 4 tons per acre reduced raindrop impact appreciably. This litter layer, in the absence of humus, holds from 0.01 to 0.09 inch of water after rain and, thereby, reduces erosion by providing time for infiltration to take place gradually. Saturated litter loses about three-fourths of its water during the first 4 days of drying, but doesn't come to equilibrium until the eleventh day (Metz, 1958). Under pine shade and litter, evaporation from the upper foot of soil during spring and summer is two-thirds as much as from bare soil in the open. One-half of the evaporation from the upper 20 inches of soil under pines is likely from the upper 6 inches (Kittredge, 1954).

There are about 20,000 pounds per acre of litter under pines in old-fields when the weight has reached equilibrium at, perhaps, age

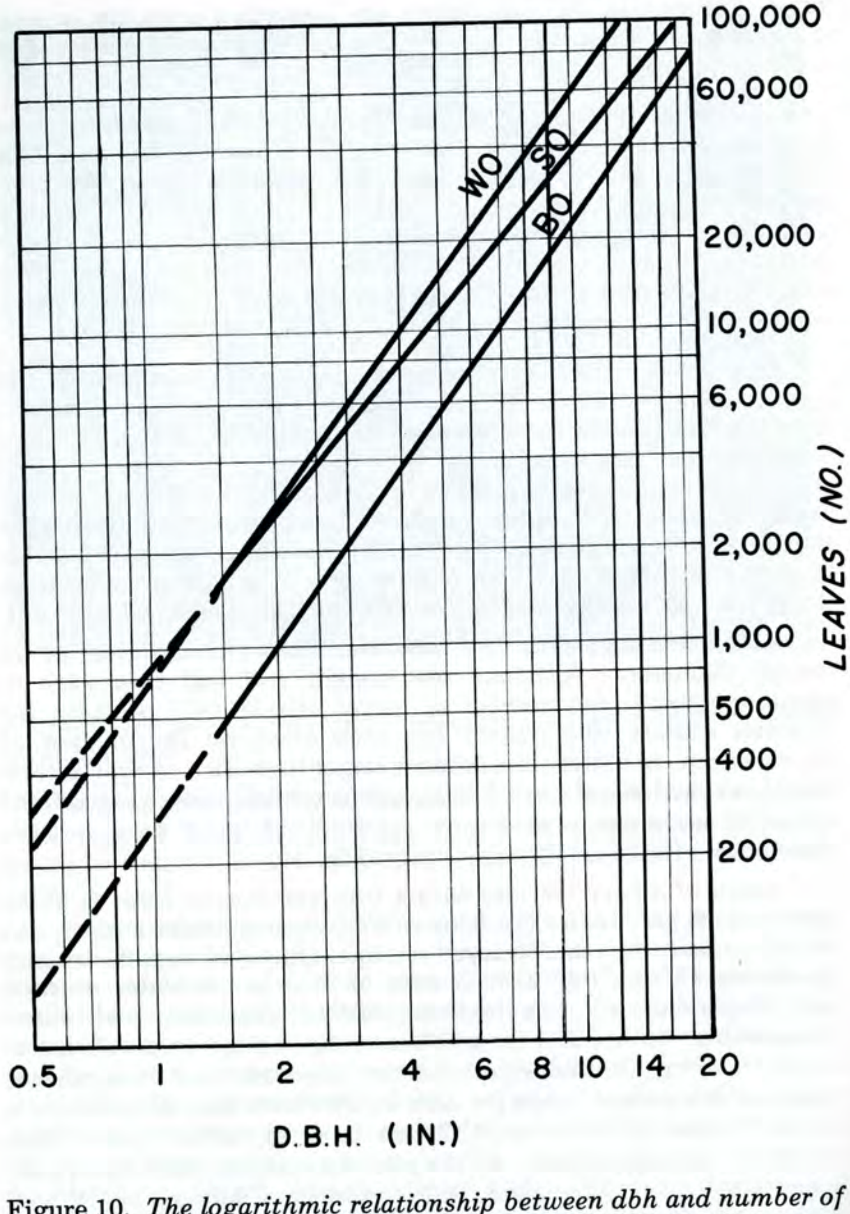

Figure 10. *The logarithmic relationship between dbh and number of leaves on trees* [*after Rothacher, Blow, and Potts, 1954*].

20 to 35. The carbon and nitrogen in conifer litter is one-half that of black locust—and probably most other hardwoods—and litter is several years behind broadleaf trees in accumulating (Auten, 1945).

Litter weight may not be reduced following clearcutting of some poor site oak stands where a thin soil mantle covers a thin mor. As an *A1* is not present and, therefore, little incorporation of organic matter with mineral soil occurs, foliage of brush and sprouts of the felled timber more than replenish the loss of leaves from harvested trees within several years. Clearcut sites naturally regenerated to shortleaf, pitch, and white pine also have as much litter 4 years later as uncut stands (Carmean, 1959).

Rain Splash - In addition to improving the soil for infiltration and percolation, leaves—before they fall—have an appreciable effect on water consumption and loss. Living foliage moderates the effects of rain splash upon the soil by reducing the heights from which drops of water directly fall. This is well-documented by Bennett, Bell, and Robinson (1951), who observed shattering of raindrops upon impact with the soil, causing particles of earth to fly to heights of 2 or more feet for distances of 3 feet laterally. When a drop falls into a thin layer of water over the soil surface, some water is forced out. The tubulent action of the water rushing back into the area where the drop fell, to replace water splashed out, throws minute particles of the surface soil into suspension—an easily-eroded state. Drop size is accountable for much of the soil so suspended and, where runoff occurs, splashing and subsequent muddying by raindrop impact is the cause of soil movement.

Raindrop impact on bare soil, especially where freshly cultivated, breaks down soil aggregates. The slaking effect of air trapped in the pores of the aggregates and the consequent dispersion of the lumps usually results in a deflocculated or pasty, viscous condition not conducive to water infiltration. Thus, regardless of how porous a freshly-plowed soil may appear, its ability to absorb water is quickly lost upon wetting by the first drops of rain.

Crown Protection - Rhododendron areas have leaf surfaces of about 5 acres per acre of land area (Hoover, 1948). These organs are helpful in reducing raindrop impact, yet provide surfaces from which evaporation occurs before storage in the soil takes place. Even trees with relatively sparse foliage, such as pines, serve as effective umbrellas for light showers. But in heavy rains, leaks occur and water drips to the forest floor. In a 10-year-old plantation spaced at 6x6 feet, 5 inches dbh, 31 feet tall, and with a basal area of over 100 square feet per acre, "throughfall" of rain did not begin until 0.02 inch had fallen; and water did not run down stems until precipitation reached 0.10 inch. Rain water reaching the ground then increased until almost as much as that which fell in the open.

Stemflow - Stemflow has been reported greatest for tallest trees and those with many branches. Sharply upthrust branches terminated by a cluster of needles form an efficient system for leading water to the tree trunk, the average loblolly pine leading 8 gallons down its stem during a 1-inch rain (Hoover, 1953). This places the water where it is readily available to roots and enables the soil at the base of trees to be soaked when ground between stems is only dampened. Because of the accumulation of twigs and needles around tree bases, and their subsequent incorporation in the soil, structure is improved and hence the area is in a favorable condition for infiltration and percolation. Surface runnoff, conversely, is retarded. This heterogeneous recharging of soil water storage, however, causes errors in estimation of soil moisture.

Where fire has consumed the organic debris at tree bases, a bare ring of crusted soil is frequently observed, washed clean of charcoal by stemflow. The favorable condition for infiltration is then lessened. Sometimes water drips from horizontal branches on old trees instead of passing down the stem to the soil.

Fire Protection - Fifteen years of protection from fire in the Valley and Ridge province, where slopes average 30 percent, resulted in summer peak runoff flow reduction of over 70 percent. Total water yield was not changed, but flow was sustained much longer than in unprotected areas frequently burned (Rothacher, 1953) (FIG. 12). In one area, after 9 years of fire protection, the proportion of total forest area in excellent and good infiltration classes increased from 6 to 26 percent (Price, 1954) (Table 12).

Figure 11. *Check dams, as well as vegetation, have an influence in controlling erosion and reducing runoff peak flows.*

Stand Treatments - Timber management and watershed management for increasing streamflow and decreasing storm damage in mountain types are subject to integration. The following treatments, while hypothetical, appear applicable for both intensive watershed management and intensive timber management (Walker, 1958).

Table 12. *Forest Land Infiltration Classes* [*after Price, 1954*].

	Excellent	Good	Fair	Poor
Canopy - percent	80+	60-80	25-60	25
Litter depth - inches	3	2-3	1-2	1
Litter ground surface cover - percent	90	90	80	75
Fire damage	--------None in recent years--------			Often or recently
Grazing	-------------------None--------------------			Generally
A1 depth - inches	4+	2	1-2	1
Soil depth - feet	2+	1½-2	1-1½	1

1. Remove dense stands of rhododendron, mountain laurel, and wild azalea in order to obtain reproduction. Generally, mountain laurel occurs on drier sites, ridges and south-facing slopes, while rhododendron is more abundant along streams and on north-facing slopes. Rhododendron causes site deterioration on southern mountain headwater streams due to increasing acidity (pH 4.6 vs 5.8) and reduction of nitrogen in litter (0.3 vs. 0.8%) (Hoover, 1948). With this brush, considerably more prevalent in uplands than in coves, little tree understory is present; but with the site opened, regeneration is established. From a watershed management standpoint, where an Ericaceous understory covers 80 percent of the area, its removal enhances streamflow and evapotranspiration is decreased. In one study, streamflow was increased significantly—the equivalent of 3 inches of rainfall the first year; and 6 years after cutting, the yield was still an inch higher than before cutting (Dils, 1953; Johnson and Kovner, 1956; Whelan, 1957).

Clearcutting can increase surface runoff during storms if soil is damaged. Shortly after opening up of sites, particularly on steep southern exposures, organic matter oxidizes, leaving the mineral soil exposed. As it dries out, the natural structure breaks down, resulting in decreased infiltration rates, percolation rates, and storage capacity. Grazing in clearcut areas, causing soil compaction, is deleterious to infiltration (Dils, 1953).

2. Control undesirable trees in upland sites in order to encourage growth of more valuable stems and to improve water yields. By order of preference, desirable species are northern red oak,

yellow-poplar, black oak, white ash, basswood, and sugar maple. Species not particularly desirable in this area are red maple, white oak (except at elevations of 3000 to 4000 feet), southern red oak, blackgum, hickories, and buckeye. With vegetation re-establishment after complete cutting of a mountain watershed, annual water yields decreased 2 inches with each increase in basal area growth of 10 square feet per acre. This indicates the increased yields attainable by removing undesirable stems (Dils, 1953). Should the yield fail to improve, it seems reasonable to suppose that water formerly used by eliminated trees is now consumed for growth by valuable stems.

In an oak-hickory forest, where trees were cut and left where they fell so as not to disturb the soil, streamflow was increased 17 area inches, or 65 percent, the first year after cutting. Largest increases occurred during summer and fall. Annual mowings of regrowth maintain much of the streamflow increase so that, after 3 years, the increase in water yield leveled off at 11 area inches. Because of the protection given to the soil, flood peaks have not increased and flow is from seepage and ground water. Where natural regrowth of vegetation was allowed, the flow 8 years after cutting was still 20 percent greater than before treatment and after 15 years was about 4½ inches above pre-treatment yields. It is anticipated this treatment effect will become negligible after 35 years. Water yields were increased because, with the reduction in transpiration, summer rainfall was frequently sufficient to raise the soil to field capacity so that free water could pass through the soil to recharge the water tables which feed the stream (Craft and Hoover, 1951; SEFES, 1955).

Radical cutting treatments such as these are less effective on south-facing watersheds than on northern exposures. Why this difference is so great is not clear since, prior to cutting, the loss of water through evapotranspiration (precipitation minus runoff) for north- and south-facing forested units did not differ appreciably in a trial in the Southern Appalachians. Nevertheless, it seems evident that similar cutting treatments for other south-facing watersheds will accomplish far less in the way of reducing net loss of water to the atmosphere. Heavier cuts will then likely be needed on south-facing watersheds to produce increases in water yield equivalent to those obtained in forests facing opposite directions. It is suggested that the ratio $\frac{\text{inches increase in water yield}}{\text{percent reduction in basal area}}$ for south-facing units is about half that for north-facing stands.

Although summer radiation is quite similar in total amount for opposing watersheds, the south slope lies at an angle to receive almost twice the radiation of the north slope in the dormant season. Quite possibly, therefore, greater evaporation loss from the south-facing watershed during the winter months may account in part for failure to get much increase in dormant season streamflow after cutting. If this is so, it is still not clear why both watersheds apparently lost about the same quantity of water to the atmosphere before the high forests were cut (SEFES, 1960).

While conversion from well-watered high forest to low vegetation provides first-year increases in water yield on the order of from 3 to 16 inches, these increases, though small, are nonetheless real and, fortunately for management purposes, occur during drier seasons when water supplies are scantiest. Indications are that the payoff in water yield will vary roughly with percent reduction in basal area; and although the water yield decreases with time as trees return to the site, it might in some instances persist many years after heavy cutting (SEFES, 1960).

3. Control undesirable stems in coves in order to release valuable trees such as yellow-poplar, white ash, and northern red oak This is also useful from a watershed standpoint since a single cutting of stream-side vegetation has been found to increase water yield slightly during summer months, even though annual increases were not significant. Diurnal fluctuation in water yields during the growing season is virtually eliminated, indicating that riparian vegetation is making heavy demands upon ground-water supplies contributing directly to streamflow. The procedure of eliminating stream-side vegetation could be of considerable importance during drought years when small increases in water yield may prevent severe mortality of forest trees (Dunford and Fletcher, 1947; Dils, 1953).

4. Thin yellow-poplar stands. This pays under intensive timber management, even as a non-commercial operation, in order to stimulate growth of crop trees. As considerable water yield is lost by plant interception and evaporation--the equivalent of as much as 12 inches annually, thinning and harvest cuttings are expected to at least temporarily reduce much of this loss. In addition to thinning at, perhaps, 10-year cycles, harvest cuttings in 25-year rotations would probably periodically increase streamflow and provide a satisfactory financial return.

Wildlife

The value of hardwood trees to wildlife for cover, dens, food, and to shade streams is recognized. Usually, the number of stems removed for silvicultural purposes will not appreciably interfere with game management objectives.

Squirrel

At least 2 trees totaling 5 square feet basal area per acre (2 trees of 22 inches dbh) are required to provide sufficient dens for an optimum squirrel population. Good den trees are those described as follows:

(1) sound, fast growing hardwood with crotches in crowns and durable heartwood.

(2) producing food as well as supplying shelter, such as white oak, maple, beech, black walnut, chestnut oak, sweetgum, blackgum, and basswood. White oak mast germinates shortly after seedfall. Those in the red oak group, germinating in the spring, are available and edible during the critical winter period (Miller, 1961).

(3) at least 15 inches in diameter (den formation takes from 8 to 30 years).

(4) now in use, as indicated by the cutting of bark and wood around the lip of the den entrance.

(5) with large cavities which, while not desired by squirrels, are used by raccoon. Cavities between 1 and 3 feet in depth are preferred.

(6) with entrance at least 10 feet from the ground. For squirrels, an entrance should not be over 4 inches in diameter. (Large entrances allow rain to enter, wetting nests; also, large entrances permit predators to enter).

(7) well-distributed throughout the forest area.

Other game trees which may be left for food and cover include shrubs and smaller species such as hawthorne, wild plum,cherry,and hazelnut; hickory trees of nut productng size; and black cherry (Uhlig, 1956).

Deer

An indication of benefit for deer of a cutting practice is found in a tabulation of browse species under 3 feet tall—the height to which deer conveniently graze. The amount of palatable browse may be about the same, regardless of intensity of cut (Morriss, 1954); or it may be more abundant after a seed-tree cutting which encourages encroachment of non-arborescent browse species, the consumption of which conserves desirable trees for timber production. However, the cleaner the cut, the greater the percentage of sprout regeneration and the sooner the browse should grow out of reach of deer. This is in contrast to "conventional" timber harvests in which valuable tree species are browsed and favorable reproduction, therefore, seriously impaired (SEFES, 1959). Mountain laurel is eaten only during food famine periods, but rhododendron is an important part of winter diet.

Browse cuts should be made on higher slopes and ridges to form a dispersal pattern for deer. Salt is sometimes effective in alleviating over-use of coves. The amount of border left for browse replenishment can be maximized by harvesting compartments of timber in such a manner as to leave zig-zag boundaries.

For cover and feed, seeding of grass and clover on fertilized skid trails, landings, and abandoned logging roads is recommended. Deer, however, do severe damage to conifers planted in skid trails. All seedlings may be browsed the first year, and most the second year, but by the third and fourth years, browse damage to surviving trees falls off to a negligible degree. A deer repellent, reported to reduce browse to 10 percent of normal, is a thick lime paste shaken from tufts of broom straw on to seedlings. The commercial "Diamond L" spray is also satisfactory (Morriss, 1954).

Removing large rhododendron and mountain laurel shrubs from heaths results in replacement with small brush. When cutting, tops should be partially severed so they fall within reach of deer. With some cambium left intact to supply products of photosynthesis to root systems for subsequent resprouting and leafing, plants will be killed within a few years by complete browsing, as removal of foliage exceeds the rate at which leaves manufacture carbohydrate for return to roots. Reserves of food are thus exhausted. Browse strips about 20 feet wide may also be cut through the brush for wildlife feed. Untreated strips should average about 25 percent of the total area so that an operable age class results when these strips are later converted to timber.

As cleared strips frequently return to Ericaceous shrubs, especially if not browsed severely, and rhododendron is a deer food of last resort, game pastures within the forest are suggested. Such sites are plowed once following the breaking of new ground and planted to permanent clover which is eventually crowded out by grass. Old house places are exceptionally favorable game pastures (Jenkins, 1953). (Turkeys find abundant insects in these pastures). The early historian, Bartram, reported that Indians developed meadows for game long before the white man's arrival.

Trout[6]

Southeastern trout streams require shade, particularly as the Southern Appalachians are the southern limit of these fish. Sensitive to stream temperature, the upper limit for rainbow and brown trout is 80 degrees F, and 75 degrees F for eastern brook trout. Water in streams flowing through cleared high elevation areas may reach temperatures of 80 degrees F, which is 9 to 23 degrees above that of nearby streams in the forests, but after meandering through 400 feet of forest, drop to 68 degrees F (SEFES, 1950). Streams flowing through a forest seldom exceed 66 degrees F, the optimum for brook trout. Streams flowing in the open at higher elevations in the Southern Appalachians have a 1 degree F rise in temperature for each 1000 feet distance in the middle of the day. Therefore, the harvesting of timber on stream banks must be carefully controlled so that all shade cover is not removed for too great a distance. In order to maintain low stream temperature and adequately stocked streams, shade trees should be retained for, perhaps, 10 chains at 10-chain intervals; but the best policy is not to cut within 50 feet of mountain streams.

[6]Good management requires plantations of catalpa to be located remote from the paths of fishermen, or else to be interplanted with bamboo in order to furnish both poles and bait. Fishermen do considerable injury to trunks, clubbing them to dislodge the catalpa worm which feeds on leaves (Weddell, 1942).

Grouse

Much less browse damage occurs to conifers planted under brush than to those in openings. For that reason, conifers may be underplanted in thickets of Ericaceous shrubs. Good cover for grouse, a marginal bird in the Southern Applachians, is thereby incidentally provided. Gradual release of the white pine is necessary which, admitedly, will reduce the effectiveness of the cover for bird protection. White pine is recommended below 3500 feet elevations while red pine and red spruce are generally substituted above this height (Morriss, 1954).

Forest Grazing [Southern Appalachians] [7]

Once believed that grazing could be condoned if the number of cattle was controlled and access limited to seasons when herbs and grasses are available (Biswell and Hoover, 1945), it is now clear that total destruction of young trees and the presence of insufficient forage rules out grazing as a product of the forest, for integrated management with timber, in the Southern Appalachians. Where grazing is essential to the economy of farm woodlot owners, small tracts best suited for this purpose should be converted to improved pasture (Johnson, 1952).

Grazing capacity for cattle in the Southern Appalachians is low: grazing for 4 months per year for 9 years has reportedly killed two-thirds of the trees. Mortality was greater in coves than upland oak-hickory or pitch-pine types due, probably, to the more palatable species in the cool, moist zones. Grass decreased in all hardwood types as a result of cattle foraging, but was not appreciably affected in pine types (Williams, 1954). Diameter growth of dominant trees is reduced up to 50 percent by overgrazing, most dramatically on the more valuable cove type species. Clearcutting followed by grazing results in sparse vegetation, especially on the lower slopes.

Native shrubs are not desired for browse, and rhododendron is toxic to cattle. Herbs, however, are utilized 100 percent the first growing season and completely consumed before cattle turn to shrubs for food. Herbs which then invade are usually unpalatable (Dils, 1953; Johnson, 1952).

Cattle are particularly damaging to yellow-poplar and white ash, especially along the streams where 75 percent of the stems below 5 feet may be destroyed the first year. Remaining seedlings, greatly weakened, produce abnormally small leaves late in the season following the year of grazing. Trees up to 15 feet tall are ridden down, browsed, and killed. Red maple and hemlock, both relatively undesirable species, replace the grazed yellow-poplar along streams, while perennial shrubs are the principal invaders elsewhere (Biswell and Hoover, 1945; SEFES, 1950). Black locust and sourwood are

[7] Conditions for the Ozark Highlands are probably similar to these for the Southern Appalachians. See Read (1956), McNamara (1960), and Vogel and Peters (1961).

also excessively browsed, while pines, hemlocks, and oaks are not.

Soil Destruction - Grazing shallow ridge soils, even for short periods, decreases soil porosity and results in compaction to the degree that water infiltration is dangerously retarded. Soils 2 to 4 inches below the surface are compacted to a greater degree than the surface 2 inches, as the top layer is lifted by frost action and wetting and drying. In the 2- to 4-inch layer, large pore space volume for water storage is reduced 60 percent in areas grazed perennially for 4 months resulting, in one July storm, in a loss of 3 tons per acre of soil and debris (SEFES, 1950).

Injurious Agents

Southern Appalachians - Fire wounds at tree bases allow rot diseases to enter and result in considerable volume losses. Yellow-poplar, according to Nelson and Abell (1953), is most resistant of the mountain hardwoods, and scarlet oak the least. While the southern pines are generally less susceptible to injury than hardwoods, this is not universally so. Sweetgum, for instance, is more greatly damaged by fire than are the pines (Bormann, 1953).

Heat kills the cambium, charred wood sloughs away, and wood is exposed to fungi entrance. Open scars are usually triangular, revealing stained or rotten wood or a hollow butt. Closed scars, from wounds overgrown with callus tissue, have about the same amount of rot beneath the scar, regardless of species. Cull in butt logs is indicated by scar length, as in table 13 (Hedlund, 1959). Open

Table 13. *Cull in Butt Logs According to Visible Scar Length* [*from Hedlund, 1959*].

Severity class	Vertical extent of scar	Cull	
		Open scar	Closed scar
	FEET	BD. FT.	BD. FT.
Minor	0.1 - 3.0	22	6
Medium	3.1 - 9.0	40	20
Major	9.1 - 17.3	59	35

wounds result in five times as much basal cull as those not open: 20 versus 4 percent of the volume. Cull percent increases with tree diameter and varies inversely with merchantable height and form class: less rot is found in tall cylindrical trees with several clear logs than otherwise.

Three-fourths of the volume culled is due to butt rot arising from fire scars, in contrast to 20 percent from top rot and only 3 percent from crooks, forks, and other deformities in stands originating from seedlings. Top cull is equal for open and healed wounds—about 3 percent (Gustafson, 1944). Trees wounded at their bases have over ten times the amount of basal defect as uninjured stems. Since virtually all (97 percent) basal wounds are fire-caused, Hepting and Hedgcock (1935) believe that eliminating fire alone in these upland hardwood stands will reduce cull to one-third of the amount in presently periodically burned areas. It is recognized, of course, that fire detection and suppression have taken giant strides in the 25 years since their prediction which, therefore, is applicable only to those areas in which fire is not excluded (fig. 12).

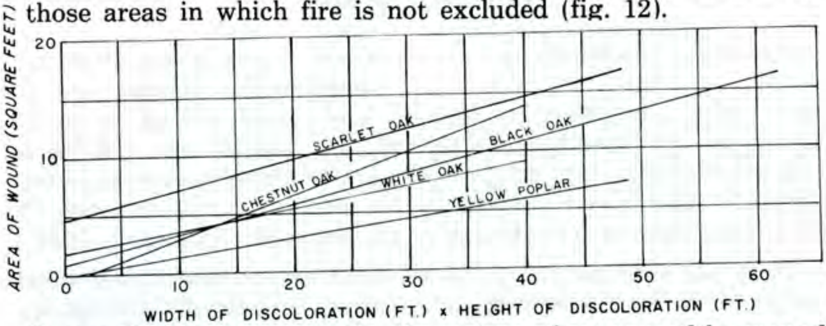

Figure 12. *To determine the dimensions of rot caused by wounding of upland hardwoods, take the product of discoloration width and height, to the nearest foot, and dbh. This is plotted for the mean dbh of trees of each species* [*from Nelson and Abell, 1933*].

Piedmont - Fire and overgrazing have been very damaging to Piedmont hardwood forests. However, the majority of trees are relatively sound, even though of low quality, and the small amount of butt rot in younger stands reflects improved fire protection. Defect is least in dominant trees. Sweetgum and blackgum have the greatest percentage affected by rots, and yellow-poplar has relatively little. Bryan (1960) reports that 86 percent of the defect is insect-caused and difficult to see on the exterior of logs. As insect losses are least in vigorous fully-stocked stands, in addition to protection from fire and overgrazing, defect can be held to a minimum by favoring dominants and co-dominants for the final harvest.

Chestnut Blight

The most important occurrence in hardwood stands of the Southern Appalachian Mountains during the past 50 years was the appearance of the chestnut blight pathogen, *Endothia parasitica*. Before the appearance of the blight, every fourth tree was chestnut—a unique species producing high-grade, rot-resistant lumber; wood pulp; tannin; nuts; and shade. It was tolerant of most sites within its range, growing on poor mountain ridges as well as in rich fertile valleys. Many chestnuts have not yet been attacked at elevations above 5500 feet.

Probably entering the port of New York in lumber shipments from the Far East about 1904, the disease was noted in Virginia as early as 1907. Eradication of infected stems never caught up with new infections so that, within 40 years, the blight extended by wind, birds, and insects to all chestnut-growing regions. The feet of a single downy woodpecker were found to carry over 7000 spores (Beatty and Diller, 1954) which, when deposited on the bark of trees, produce spore horns that exude from bark pustules. Dissolved by rain water, the minute particles are washed into bark wounds. Other spores are shot from pustules into the air and carried great distances by wind. Upon infection, host trees are killed by spreading of the fungus mycelium in the inner bark and, occasionally, in the sapwood.

Being a prolific sprouter, coppice shoots follow death of above-ground chestnut organs and these sprouts live, perhaps to bear seed, before the blight fungus attacks again.

Efforts have been made to develop *Endothia*-resistant strains and to introduce oriental species, such as Chinese chestnut. While Chinese chestnut is less susceptible than American chestnut, it must be grown on excellent sites. In the Piedmont, its form is too poor to compete with native timber trees and its fruit is an inferior substitute for the edible nut of the American chestnut (MacDonald and Thor, 1967; Little and Diller, 1964; Clapper, 1963; Jaynes, 1967; Diller and Clapper, 1965).

Species Replacement - Sites left vacant by the species' decline have been captured by both favorable and unfavorable types. Release of understory hardwoods upon death of the chestnuts was so gradual that crowns of residual trees filled openings which were too small for establishment of reproduction, taking 9 to 15 years to reach maximum annual growth. On mesic sites in the Great Smoky Mountains, hemlock, yellow-poplar, Fraser magnolia, white basswood, sugar maple, chestnut oak, and northern red oak took over (Woods and Shanks, 1957). Above the coves on dry slopes and ridges, chestnut has been replaced by species more xeric than itself: sourwood, scarlet oak, and pitch pine. Black locust and yellow-poplar are temporary components, locust borers and leaf miners reducing the former; while intolerance to shade of yellow-poplar precludes its appearance in the overstory, barring clearcutting or catastrophe, and eventually causes its elimination. All oaks together comprise about 40 percent of the replacement species in the Great Smokies (Woods and Shanks, 1959).

Present composition of stands in the southern Blue Ridge territory indicates that the oak-hickory climax will be attained, although the time is too short since chestnuts began to die for equilibrium to be established. Northern red oak and white oaks are most abundant on middle slopes, sites where the oak-chestnut climax was most stable (Keever, 1953). Mixed mesophytic forests also replaced the chestnut type in the Cumberland Plateau of Tennessee (Caplenor, 1954).

In some highlands of the Southern Appalachians, yellow-poplar is the most important replacement. Basal area for the species increased from 3 to 13 square feet per acre in the 20-year period subsequent to 1934, at which time 40 percent of the oak-chestnut type was chestnut. Sourwood, cucumber magnolia, sweet birch, yellow birch, and hemlock, not present when chestnut was a major component of the stand, invaded due to fire and cattle exclusion (Nelson, 1955).

It is noted that even before the appearance of the chestnut blight, disease was an important factor in the evolution of upland forest composition. The ink root rot disease, caused by *Phytophthora cinnamomi*, for instance, was epidemic in the southern United States from 1825 to 1875 and, according to Woods (1953), was responsible for eliminating many chestnut stands.

Nectria

Cankering caused by *Nectria* spp. fungi, most frequent and severe at high elevations, may be correlated with altitude. In the high country, cankers are most common in stands of soft maple, black birch, yellow birch, and cherry, all of which are weed species. In contrast, stands of white ash, white oak, elm, scarlet oak, and beech have little *Nectria* infection. This may be due to the favorable site conditions which prevail for establishment of stands of desirable species. Likewise, the probability of more cankers on poor sites may be because such sites have a preponderance of susceptible hardwoods (Grant and Childs, 1940; Spaulding, Grant, Ayers, 1936).

Some degree of *Nectria* control is obtained by maintaining well-mixed, vigorous stands. At high elevations, conversion of birch-maple forests to conifers is suggested. Removing soft maples which harbor the canker-forming fungus and periodic sanitation cuts are also recommended to free sites of diseased trees. Unmerchantable stems should be girdled or felled and slash of merchantable trees should be burned.

Dutch Elm Disease

All species of native elm in the United States are vulnerable to attack by this disease. While cures are yet hypothetical, most economic damage is done to city shade trees rather than to forest stands. The fungus vector is the European elm bark beetle (Buchanan, 1965).

Oak Wilt Disease

Pathologists consider several sources of inoculum causing the spread of oak wilt: fungus mats, root grafts, and bleeding wounds. The latter are believed most important. Ax cuts, insect holes, and branch stubs hold water in which the fungus has been isolated. Insects may also be a vector (Craighead and Nelson, 1960). Increment borer wounds act as penetration points during brief periods when fresh fungus mats are available to insect carriers (Hart and Wargo, 1965).

Detection is generally by aerial observation, including infrared photography (Roth, Heller, and Stegall, 1963). Control possibilites include chemical girdles with 1:1 water solution of 40% sodium arsenite in a 10% solution of sodium pentachlorophenate (Ohman, Anderson, and French, 1959) and spraying all branches of infected trees larger than 3 inches diameter after cutting the currently wilting trees with 0.5% gamma isomer of BHC and 2% pentachlorophenal in No. 2 fuel oil (Boyce, 1959).

Elm Spanworm

The elm spanworm, in adult life known as the snow white linden moth, has, in very recent years, resulted in wood-growth loss and wildlife loss—through a shortage of mast— in North Carolina, Tennessee, and Georgia. Although spread of the insect's damage has been from several small spots in 1954 to about a million acres in 1961, it now appears that infestation has reached its peak and will shortly subside. The order of preference of species upon which the larvae feed is: hickories, oaks, walnut, maple, and beech. Neither yellow-poplar nor sassafras is attacked. The adverse effects of repeated defoliation are manifested for several years in reduced vigor growth loss, and mortality.

Barrel-shaped, olive-green eggs are deposited in June on branches and bark in irregular masses. These eggs hatch in late April of the following year. The spanworm larvae, or loopers, green to brownish in color, immediately feed on new foliage and may defoliate the host tree in 5 weeks. They then pupate in crumbled, folded leaves or in strings of self-spun silk, emerge as pure white moths in 2 weeks and lay their eggs the following week (Fig. 13). Long-distance migration by the adults accounts for the pest's rapid spread (Speers, 1958: SEFES, 1959).

DDT at a concentration of ½ pound per gallon of fuel oil and at a rate of 1 gallon of mix per acre provides effective control without harming fish or game in the vicinity of treated areas.[8] Biological control measures, such as introductions of egg parasites—on parasitized egg masses—to new outbreak areas, may be appropriate (Ciesla, 1963).

Hickory Twig Girdler and Spiral Borer

Terminal shoots of hickory reproduction are often killed by the hickory twig girdler and the hickory spiral borer, resulting in misshapen trees.

Numerous parasites generally keep these insects in check. Some protection is suggested by removing old hickories from the vicinity of reproduction (Beal and Massey, 1942).

[8]Correspondence with C. L. Morris, Virginia Forest Service.

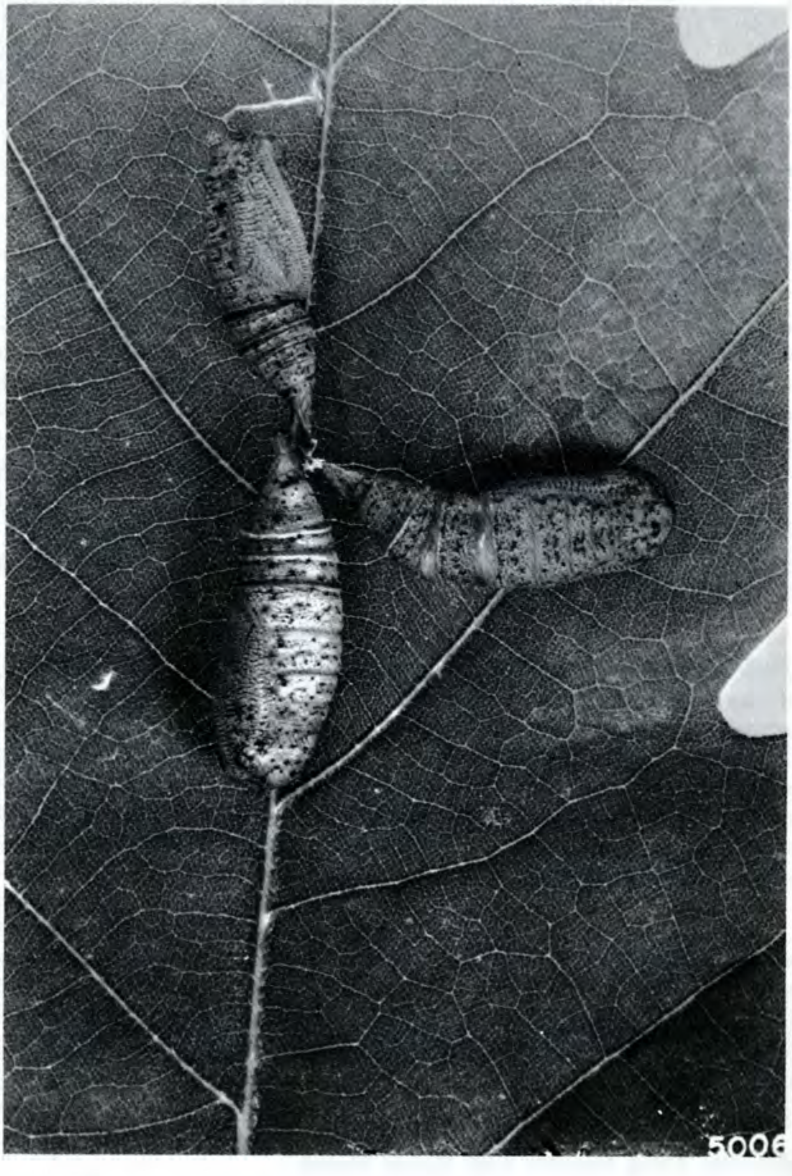

Figure 13. *Elm spanworm pupae [from Speers, 1958].*

Storms

Glaze storms, frequent in the Southern Appalachians at elevations above 3,000 feet, account for poor tree form, windshake, and wormy and diseased timber at middle age. Pole-size trees with even crown canopies are possibly the most severely damaged. Scarlet oak and black locust are the most seriously damaged species while white pine and hemlock are highly resistant (Abell, 1934).

White oaks, especially large overmature trees, are frequently killed by late freezes. Apparently buds as well as new leaves are frozen to death, otherwise new leaves would appear. While white oak occurs high in the mountains, Beal (1926) observed that only in valleys and hollows did death due to freezing occur. Possibly it was a phenologic response difference—buds or leaves of trees in low areas being more advanced than those at higher elevations—or wind in the valleys was insufficient to move the cold air out and over the mountains.

Fire

Repeated burning results in erosion, exposing soil to be baked in the sun, compacted by rain, and released of its organic matter through oxidation. Three fires, however, did encourage an abundance of legumes for quail and deer food (Keetch, 1944).

COASTAL PLAIN

Four major broadleaf forest situations occur in the Coastal Plain: high hammock lands, hardwood-pine types, bottoms, and swamps (Vande Linde, 1960). Although the first two are relatively unimportant either in area involved or as a potential source, they require mention here.

Hardwood-Pine Types

Hardwood-pine types, generally occurring adjacent to streams, bottoms, and swamps, are high quality pine sites and produce above average hardwoods. This mixture should be maintained. Whether pine or hardwoods are the prevalent species is generally attributed to past fire history.

Deciduous trees with rot should be removed first, most of which occur in old-growth unmanaged stands of tupelo and red maple which have had little fire. Even in stands 100 years old, broadleaf trees make up perhaps only a tenth of the commercial volume, a low value because of deduction for rot. Where loblolly pine volume was 22.5 MBM and broadleaf trees 1.8 MBM, Gruschow and Trousdell (1959) obtained the following data:

Species	Trees with rot	Volume deduction for rot
	Percent	**Percent**
Yellow-poplar	16	4
White oak	21	4
Other oaks	19	7
Sweetgum	13	5
Tupelo gum	30	13
Red maple	57	38

High Hammocks

The high hammocks, uplands of deep, loamy sands, are good pine sites. As broadleaf trees thereon include live oak, southern red oak, sweetgum, and hickory and are, at best, only of fair quality, these sites should be converted to conifers. Where conversion is impractical, as in the oak coppice stands of southern New Jersey, black oak is favored because of its fast growth and relatively few sprout stems per clump. Chestnut and white oaks are the next preferred species (Wood, 1939). Post oak has fewer sprouts per stump, but its growth is slow; and scarlet oak, in contrast, is faster-growing than black oak, but has many sprouts.

Bluff Hills

Lesser broadleaf sites of Coastal Plain uplands include the Bluff Hills adjacent to the Mississippi River Delta where preferred species are cherrybark and shumard oaks for all sites and white ash and yellow-poplar on the lower to middle slopes. Stands growing 500 board feet per acre annually indicate the Bluff Hills are ideal sites for broadleaf forests, cherrybark oak exceeding ½ inch per year radial growth. Johnson (1958) notes that the timbers here are freer of borer insects than the bottomland deciduous trees of the adjacent Delta. In the coves and bottoms that cut through the Bluff Hills, cottonwood, yellow-poplar, white ash, and black walnut are preferred, cottonwoods growing 30 inches dbh and to 5 merchantable logs in 30 years.

Sandhills

Two areas having similar vegetation—scrub oaks—and soils—deep sands—are the Fall Line Sandhills of the Carolinas and Georgia and the West Florida Sandhills. These trees are presently considered non-commercial. Silvicultural treatments are designed to convert the worthless scrub to conifers.

Post Oak Zone in Texas

The Texas Post Oak Belt, lying to the west of the pine-hardwood forests of East Texas, is transitional to the blackland prairies to the west. Trees are principally post and blackjack oaks. Growth is slow, form is poor, coppice stands predominate, and soils are rather xeric sands. Future timber needs may require utilization of these presently non-commercial forests for wood for pallets and pulp. Conversion to loblolly pine is feasible when such is needed.

INTERIOR HIGHLANDS

Hardwood forests occur in pure stands—principally white oak—and in mixtures with pines and eastern redcedars in the Interior Highlands of Arkansas and Missouri. Management practices are similar to those in the southern Appalachians, but trees grow more slowly principally because of less rainfall.

Cross Timbers

The Eastern and Western Cross Timber of Texas, large "islands of scrub oak," offer an unusual situation for broadleaf forests. Sandy soils predominate, in contrast to the red clay hills and brown sandy loams of the East Texas upland forested areas. Either grass or trees are capable of withdrawing all available moisture from the upper 2 feet of Cross Timbers' soil; but grass has a tendency to draw first from the upper foot and, only upon exhaustion of that zone, depletes moisture at lower levels. Scrub oaks draw from surface and subsoil levels simultaneously. During the growing season, Koshi (1959) found that soil moisture, utilized by trees and grass at maximum rates of 0.2 inch per day until the wilting point is approached, is appreciably greatest in cleared lands.

In the Cross Timbers, oaks (post and blackjack) therefore should be maintained on steeper, rougher slopes to hold the naturally erosive soils and to reduce excessive runoff (Baudendistel, 1941). The number and duration of periods of moisture stress, however, may be reduced by drastic thinning of the scrub oak stands (Koshi, 1959). Other areas may be converted to improved pasture.

Interior Low Plateaus of Kentucky and Tennessee

Central Kentucky and Tennessee are characterized by soil of calcareous origin which excludes pine types. Most of the forests there are of the oak-hickory cover type, but many other species occur, due, especially, to the effect of local topography.

Such forests are described as transitional between the mixed mesophytic of the Southern Appalachian to the east and the drier prairies to the west.

High productivity of these lands for agricultural purposes, if protected from erosion, suggests further clearing of forests will likely occur. Silvicultural practices should encourage walnut plantations on better forest sites, black locust on spoil banks, and eastern redcedar on shallow-soil glades invaded by scrub hardwood. Existing stands of mixed hardwood should be upgraded by species and quality.

Black Walnut Plantations for the South[9]

Substantial financial returns can be realized by managing black

[9]Leonard A. Lankford, Jr., assisted with this section.

walnut in plantations to produce large, exceptionally straight, and defect-free trees selling for $1,000 per thousand board feet. Unlike softwoods, fast-grown walnut wood has a high specific gravity, machines well, and exhibits dark heartwood. Although some have reported plantation failures and, consequently, have recommended planting black walnut only in forest openings or on farm land not suitable for agriculture, this guide presents new information on site selection and management as well as tree spacing, planting, and pruning.

Site Selection

Natural black walnut sites have specific texture, subsoil depth, drainage, reaction (pH), and mineral nutrient level characteristics. The best soils are sandy loams underlaid by clay subsoils and deep alluvial soils. These are commonly found under undisturbed hardwood forest. Soil texture as fine as silty clay loam may be suitable.

Soils without pronounced subsoil development, recognized by easy digging, are best. The subsoil depth should be 24 or more inches, although 18 inches may be adequate in some soils. Auten (1945) showed soils with a thinner surface layer have site indexes less than 60 and are not economical for sawtimber production.

Soil should be permeable enough so that excess water from heavy rains is removed rapidly, yet enough remains to insure high water storage within the root zone. Indications of proper drainage are a yellow, brown, or reddish-brown subsoil without pronounced gray or red mottling and a ground water table 3.5 feet or more below the surface.

The optimum range of pH is 6.0 to 8.0. But only when the pH is below 4.6 or above 8.2 are corrective measures needed. Thompson and McComb (1962) found growth of trees in plantations correlated with pH.

The most important mineral nutrient is calcium. Increasing amounts of soluble iron and aluminum decrease site index, probably because these elements make calcium unavailable. Nutrient deficiency symptoms are described by Finn (1966) for major and minor elements.

Site Management

Although site quality may be sufficiently improved to get maximum growth on below-average sites, even the best lands may need fertilization, weed control, and moisture control (irrigation or drainage).

Manuring, mulching, and fertilizing new seedlings is recommended if potential income can justify costs. When a severe nutrient deficiency is obvious from foliar symptoms, or when nutrient content is below levels shown in Table 14, fertilization is necessary.

TABLE 14

Optimum ranges of nutrients of black walnut (from Finn, 1966)

Series	Optimum Range pounds/acre
Nitrogen	400-600
Phosphorus	200-360
Potassium	400-900
Calcium	360-480
Magnesium	160-240
Sulfur	40-80

Mature walnut trees fertilized with ammonium nitrate pellets have grown 34 percent faster in diameter than unfertilized trees. Upland trees are expected to benefit most from fertilization.

Byrnes (1966) has shown that competition of weeds and brush for light, soil moisture, and nutrients must be eliminated not only before planting but throughout the growing period. Hardwoods can be controlled initially by bulldozing, and then the sprouts treated with silvicides. Yearly cultivation with a disc plow will economically control grass and weeds. Cross cultivation is the usual method, but **single-pass** cultivation with an offset double-gang disc and a grape hoe may be more economical. Strip cultivation is helpful, but complete control is best. Contour plowing and terracing may be necessary to prevent erosion.

During hot summers, the soil may dry to a depth below the root zone, especially if the plantation is on southwesterly facing slopes. In many cases irrigation and/or terracing may be effective in increasing growth on dry soils, just as tile drains might on wet lands.

Spacing

Krajicek (1966) shows that spacing should increase with age for maximum utilization of site and rapid diameter growth. Initially, spacing of about 18 x 18 feet is recommended (Figure 14), then when the tree reaches 12 inches dbh (small sawtimber size), half of the stems should be harvested, leaving a spacing of 26 x 26 feet. It may be necessary to again thin the plantation when the trees reach about 16 inches dbh so that one-half of the trees are left, spaced at 37 x 37 feet. These should be grown to 30 inches dbh for the final harvest.

Figure 14. *Recommended spacing for walnut plantations at various stages of development.*

Planting

Geographical races of walnut have been recognized but their significance is not known. One genetic variety has been improved. This is the Thomas, a particularly vigorous tree producing high-quality nuts. An effort should be made to obtain this variety for planting, even though it is probably not yet available for general distribution.

Because seeds are cheaper, easier, and faster to plant than seedlings (and because there is no ready supply of walnut seedlings), planting nuts is recommended (Erdmann, 1966).

If available, nuts should be collected from healthy, well-formed, forest-grown trees in the general area of the plantation. After eight years, the plantation itself will supply them. Sound nuts, recently collected and unstratified, can be separated from defective ones by placing the husked ones in water. Defective nuts will float while sound ones sink. Seeds are believed to remain viable in the litter for up to five years (Sander, 1966).

Seeds should be planted about one inch deep for most rapid seedling emergence, and no deeper than two inches. They can be planted individually or in small groups. If several are planted together, each seedspot should be thinned early in June, leaving only the best seedling. To prevent sprouting, seedlings should be cut below the root collar.

When the ground is soft, nuts can be pressed into the soil to the proper depth with the heel of the shoe, or a stick can be used to punch holes to receive them. Loose soil is then kicked over the planted nut. If several nuts are to be planted in one spot, they should be pressed in, about three or four inches apart, and covered. If the soil is not wet or soft enough for pressing in the nuts, holes may be dug and a two-inch layer of firmly packed soil placed over the nuts.

Walnuts can be planted in either the fall or spring, but spring planting is more common because of the rodent problem (no "sure" rodent repellent has been developed for walnut seed but Arasan-endrin has provided fair protection (Russell, 1968). The time of planting makes little difference as far as germination is concerned. In general, however, fall planting is easier because removing the husks and special stratification is unnecessary. Fall planting, since it is easier and cheaper, is recommended when it is apparent that cultivation will control the rodent population and wire covers will be used to protect seedspots.

Spring planting requires prior seed stratification (Figure 15). Nuts cannot be stored in stratification pits longer than one winter because they will sprout. Before visible germination has occurred, seeds should be planted by "pressing in" or "hole" methods. In the event some sprouted seeds are discovered, care must be taken so that tender roots will not be damaged when they are planted.

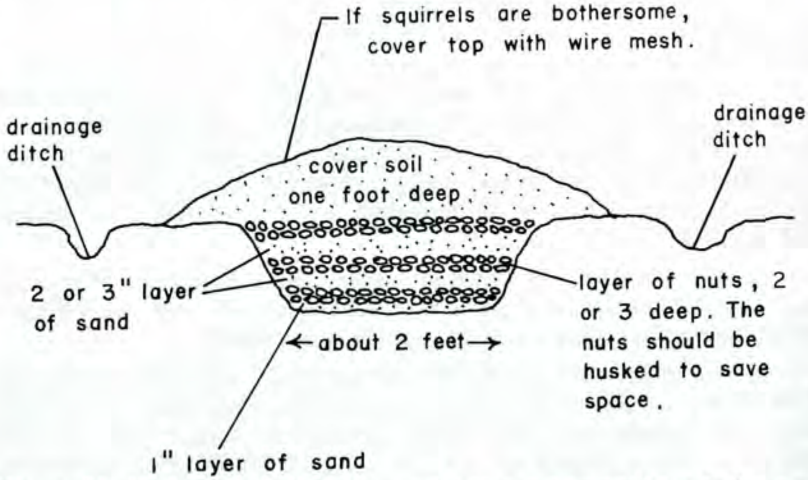

Figure 15. *Walnuts stratified in a pit* [*also a box or frame*] *for over-winter storage.*

Black walnut has grown satisfactorily when planted on lower slopes of mine banks under pine plantations (Deitschman, 1956). Large planting stock is most readily established (Williams, 1966).

Pruning

Although pruning produces trees with long, straight, clear logs, these will not be good nut producers. Pruning does result in epicormic branching. Eventually, pruning will result in better bole form because of increased diameter growth high in the tree. With pruning equipment available today, walnut growers can economically produce at least 25 clear feet on the best sites. No significant natural pruning can be expected of plantation-grown trees.

For the first few years of growth, Clark (1966) suggests snipping off all leaders of each tree several times during the growing season, **beginning in the first May or June after planting. Under intensive** culture, the trees will grow so fast that excess leaders may ruin the shape of the tree within a month; therefore, monthly checks are recommended.

Should badly misshapen and angled trees emerge, they must be cut off with a clean, slanting cut just above the ground line. Later, excessive sprouts from the cut stem are removed and one stem cultivated. This coppicing should not be done after mid-July because tender sprouts may be killed by winter frosts.

Pruning for clear length can begin in the fall of the third year when the branches are small and pruning is inexpensive. An eight-point, curved pruning saw is recommended. The cuts should be as close to the trunk as possible to lessen the danger of forming loose knots. The year after severe pruning, the trees need to be trimmed of the small, soft sprouts which develop.

After trees are five years old, no more than 25 percent of the live crown should be removed at a time. Growth will slow if more is pruned, and prolific sprouting may result. Periodic pruning should be done in the fall at one- or two-year intervals, or at shorter invervals if an inspection shows that sprouts are excessive. At the same time that the lower crown is pruned, sprouts should be removed. Pruning should continue until a clear bole of the desired length is obtained. Pruning wounds of small branches will heal rapidly and no decay will result.

Protection from Damage

The thick dark and durable heartwood of walnut trees also make them resistant to fire damage and accompanying decay. However, domestic internal stain, wounds, and degrade may result from increment borings (Clark, 1966).

Grazing animals should be fenced out of plantations so that no trampling or soil compaction will occur. Fire must be excluded.

Principal diseases include an anthracnose affecting leaves and darkening nutmeats. Walnut bunch, a witches' broom, is caused by a virus. Wood of diseased trees becomes brittle, branches die back, and trees die. White trunk decay of heartwood, a *Fomes* fungus, and brown decay of heartwood, caused by a *Polyporus,* enter through bark injuries and dead branch stubs. *Nectia* cankers are not uncommon, but heal most readily when trees are on good site. A dieback fungus, *Melanconis juglandis,* slowly kills trees (Berry, 1966). Lethal defoliating insects are the elm spanworm (*Ennomus subsignarius*) and the walnut caterpillar (*Datana integerrima*). These are readily controlled by BHC. Many other insects, rarely epidemic, consume leaves and nuts. Natural predators keep them in check (Hay and Donley, 1966).

Expected Growth and Yield

The best site index data available were prepared by Kellogg (Figure 16). It should be noted that these curves are only

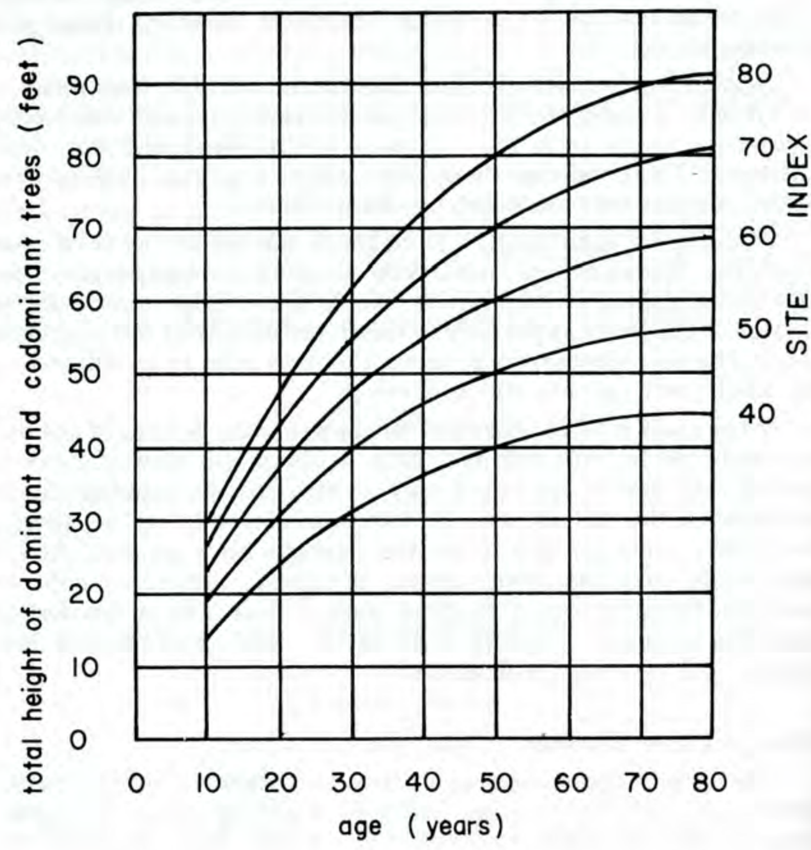

Figure 16. *Total height of dominant and codominant trees [feet].*

approximations since early growth is not consistently indicative of future growth. Also, the plantation grower may find that his plantation is exceeding the growth of Site Index 80, the highest curve in the figure. One 25-year-old plantation with dominant trees 84 feet tall has been reported, exceeding all previously known growth records for walnut. One may theorize that walnut will grow at the rate of one-half inch radius, or one-inch diameter, a year. Growth rings of one-fourth inch are common now, even on unimproved sites and without management. A 30-year rotation, growing the final trees to 30 inches dbh, is recommended. Spacing and thinning schedules (presented below) produce the yield estimation given in Table 15.

A yield of 26,000 board feet and $24,500 per acre in thirty years is a liberal estimate for plantations. It is not, however, impossible.

TABLE 15

Yield Estimation

Initial Spacing Feet	Initial Trees per acre	# Trees Cut/ Acre	Age Cut	Avg. DBH When cut	#Clear logs cut each	Vol. Cut/ Acre bd. ft.	Value MBM	$ Return/ Acre
18.4x18.4	130	65	12	12	1	1885	$250	471
26.0x26.0	65	33	16	16	2	3993	1,000	3993
36.8x36.8	32	32	30	30	2	20032	1,000	20032
						25710		24,496

While hickories are important components in the broadleaf forests of the South, their importance rests principally upon numbers rather than quality or usefulness. They are usually outgrown by oaks and yellow-poplar. Considerable resources are being expended for determining outlets for upland hickories but, to date, this has not resulted in a demand for silvicultural knowledge as to how to treat the species. Hence, most of that which follows concerns the oak constituents of the oak-hickory community.

Wildfire is a principal cause for the present condition of oak-hickory forests throughout the region. Mortality of younger or smaller stems, as well as disease infection, is much greater than for trees 5 to 7 inches dbh (McCarthy, 1935), so the importance of fire exclusion in oak-hickory forests, especially until trees are more than 10 inches dbh, is cited (Fig. 17).

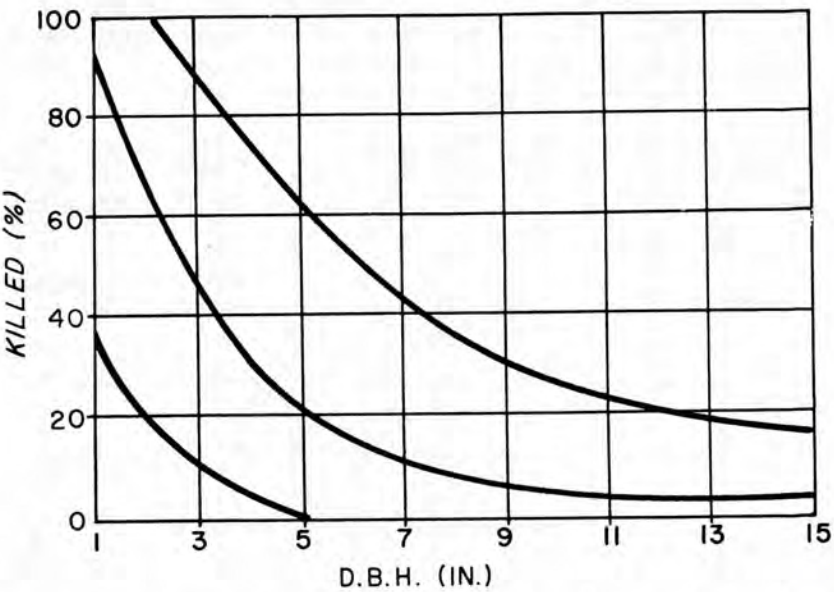

Figure 17. *Oak tree size vs. mortality for three fires in the Southern Appalachians [after McCarthy, 1935].*

In addition to the Southern Appalachian Mountains and the Piedmont, post oak-blackjack oak sites occur in the (1) flatwoods belt of Alabama where heavy soils are waterlogged during rainy seasons, and dry and hard at other times, (2) poor soils of the upland Coastal Plains, west of the Mississippi River, (3) dry ridges with sandy slopes and steep southern slopes of the Ozark, Boston, and

Ouachita Mountains of Arkansas, (4) open xeric plateaus of the western border of the Ozarks, and (5) savanna climax areas of Texas and Oklahoma where forests transition to prairie (Bourdeau, 1954).

Growth

Southern Appalachians

In many locales, the rapid diameter growth, exceeding 3 inches in 10 years, is comparable to that of yellow-poplar on the same sites. Quality of the growth, however, varies. The potential of the type is indicated by a stand on the northern slope of a mountain cove which was cut to a 13-inch dbh limit that left 1.2 MBM and 30 square feet per acre basal area. In the following 32 years, in which the stand received no cultural treatment, it increased to twice the number of stems, 3 times the basal area, and 5 times the volume. Annual growth for the period amounted to 2.1 square feet of basal area per acre and 185 board feet. An uncut stand had at the end of the period less trees, an increase in basal area volume of only 1½ times the original, and annual growth of 1.1 square feet of basal area and 105 board feet per acre (Williamson and Sander, 1957).

Another stand in which growth potential is demonstrated is the Sosebee cove of North Georgia. It is site II on the S.C.S. scale, slightly above 3000 feet elevation, and facing north. Although both soil and timber appear virgin, the area may have been cultivated. Northern red, white, chestnut, scarlet, and black oaks; yellow-poplar, hickories, and white ash are the principal species. When the stand averaged 58 years of age, it contained 28.6 MBM per acre in 111 trees 12 inches dbh and over. Average annual growth then was about 500 bd. ft. per acre (AFES, 1934).

Piedmont

Hardwood-producing coves and lower slopes occupy about 9 percent of the Piedmont province of Georgia (Nelson, Ross, and Walker, 1957). While this figure would not be far amiss for the entire province, from Maryland to Alabama, much more than the coves and lower slopes are good hardwood sites from North Carolina northward, with basal areas of 150 square feet per acre.

The post oak-blackjack oak type is restricted to the south-facing bluffs with rocky, eroded sites, or to soils characterized by impervious and plastic clay within a few inches of the surface. Northern red, black, scarlet,and white oaks are almost excluded on these sites. Stocking is poor, canopies do not close, and trees rarely exceed 30 feet in height.

Variants of the oak-hickory types, determined by site, are white oak-black oak-red oak, and white oak-post oak. The former is a favorable deciduous type for mesic uplands, generally on north-facing slopes. The latter occurs on dry ridges and knolls where it has 20 percent less basal area than the white oak-black oak-red oak type, and relatively less white oak (Bourdeau, 1954). Shade intolerance and slow growth excludes xeric species from northern slopes while insufficient drought resistance prevents mesic species from dominating dryer south-facing sites. Neither soil fertility nor pH is influential, but microclimate—as it affects overwintering seed, light, plant competition, and resistance of soil to root penetration—may be responsible.

Figure 18. *A climax white oak-hickory forest of the Southern Piedmont.*

Ozark Highlands

Oak forests in the Ozarks are in the initial stages of management designed to raise the volume of the growing stock and to increase the rate of growth. Protection from fire, insects, and disease is essential. Average volume of these oak forests does not exceed 800 board feet per acre: 3000 feet per acre rarely attained. Average growth for all oak forests of the region is possibly 50 board feet and, again, 100 board feet is exceptional. The growth rate is probably less than 3 percent per annum. Perhaps one-third of the gross volume of the hardwood forests in the Ozark Highlands is cull and of non-commercial species (Clark and Liming, 1957) (Fig 19).

Figure 19. *Typical low-grade hardwood stand on an Ozark upland site [from Clark and Liming, 1957].*

Moisture Relations

The moisture demands to oaks and hickories appear to vary among the many species in each genus, although there is little documentary evidence to substantiate this. Hursh and Haasis (1931) noted that chestnut oak (and pitch pine) survived the effects of severe summer drought much better than did black oak. Stagheads of black oak are more common than for chestnut oak on shallow soils.

Imbitional water values—the difference between the moisture equivalent and the xylene equivalent of a soil, a measure of the soil's ability to absorb water—for the B_2 horizon of oak sites ranges from 3.7 to 9.5. Within this range, soils are friable and tree roots free to grow at considerable depths, frequently below 8 feet. The imbitional water value is also within the range where water levels fluctuate and where both temporary and permanent water tables in the B_2 zone influence site index.

Radial growth of red, chestnut, and black oak do not appear to be related to rainfall patterns, indicating these species are not as sensitive to low soil moisture as, for instance, yellow-poplar (Tryon and Myers, 1954). On the other hand, radial growth of white oak in western North Carolina was found dependent upon the amount of precipitation and its distribution over a 15-month period (Schumacher and Day, 1939).

Radial increments in dying scarlet oaks 30 to 90 years old are reduced when rainfall deficiencies occur in the West Virginia mountains (Tryon and True, 1958). This generally occurs in medium-texture shallow soils derived from tilted shale and, therefore, subject to excessive drainage. The soils are infertile and range from SI 43 to 58 for scarlet oak (yet average 66 for other oaks which, like hemlock, are not affected). Reductions in diameter growth, the same for healthy as dying trees are associated wtih dry periods during the preceding July to September. Individuals on the poorest sites have least growth and do not recover as readily as on better sites. Because trees on better sites are not affected by early drought years in a consecutive series, but later respond to the build-up of moisture stress, the malady appears pathogenic and may be confused with oak wilt or other diseases. The occurrence of fungi which are secondary invaders after death further confounds diagnosis.

The drought resistance of post and blackjack oaks is of the "primary active" category. This is evidenced by [10] the greater water deficits which occur within the plant when soil is at the wilting point and (2) the ability of primary active species to recover with greater vigor than do non-drought-resistant species when moisture is supplied following periods of drought. Apparently tissues withstand considerable desiccation and yet regain turgidity when adequate water is restored.

Bourdeau (1954) noted that survival of northern red oak is related to soil type and the amount of water available during summer dry spells, the latter largely a function of soil type (Fig. 20). The Georgeville soil of his experiment was SI 81 for mesic species; and the Orange was SI 58 for xeric post and blackjack oaks in the Piedmont. Depth to which roots grew the first year did not differ between species or soil, but plastic clay at 4 inches hindered root penetration in the Orange series, even when moisture was maintained at a favorable level. Thus, it is not alone an ability to penetrate hard soil that maintains these species on xeric sites. Based on root growth, it might be surmised that drought resistance works inversely to that which is observed in nature. Shoot: root ratios, as they affect transpiration and the amount of moisture-absorbing root

[10]This occurs when plants have the ability to withstand dehydration rather than to prevent dehydration (secondary active, like cactus), or to enter into a resting stage (passive, like ferns, moss, and lichens).

surface, could indicate drought resistance; but this ratio seems to be more closely allied between species by taxonomic than by ecologic relationships.

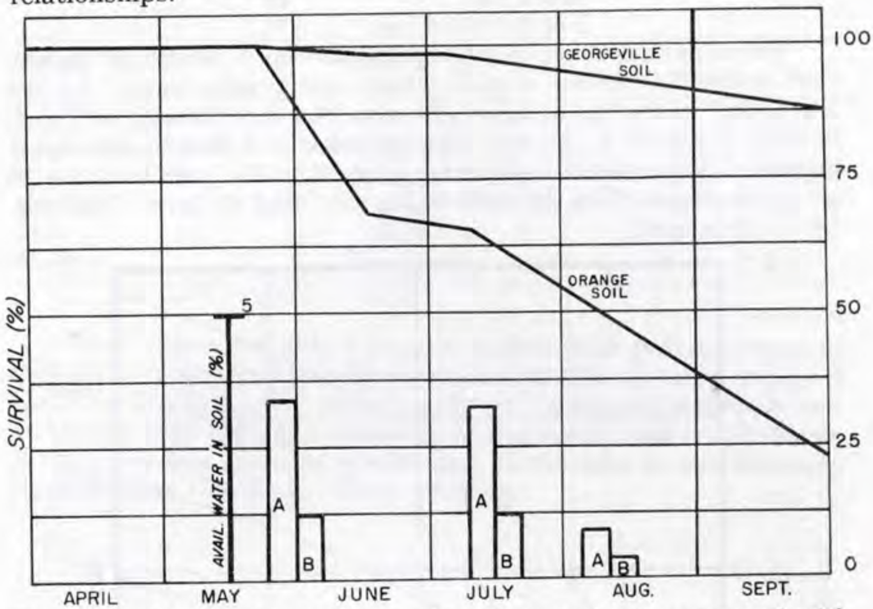

Figure 20. *Survival percentage of northern red oak compared with available soil water [from Bourdeau, 1954].*

Maximum transpiration for all oaks occurs when soils are at moisture equivalent. It is one-third of maximum when moisture has been reduced to the wilting point. Transpiration is further decreased when oaks are flooded for periods of more than a few days. Buttressed root collars develop under inundated conditions, and many new roots form above the soil surface but just under the water. Effects of flooding do not vary by oak species (Bourdeau, 1954). Parker (1950) showed the decrease in transpiration rate for spring-flooding and the resumption of transpiration following drainage for several species. Although the mesic northern red oak reaches its peak of photosynthesis at relatively low light intensities and the xeric blackjack oak is at the other extreme, soil moisture bore no relationship to photosynthetic rate for either species.

Site Index

Southeast

Olson's curves for upland oak (Fig. 21) are for the Virginia-Carolina Piedmont and the Southern Appalachian Mountain regions. Although site index for white, southern red, black, scarlet, and northern red oaks is somewhat higher for the Piedmont, growth rates of black and chestnut oaks do not differ for the two zones. Mean site index for the Piedmont region is about 74. For white, southern red, and black oaks, the average is about SI 70; scarlet and northern red oaks about SI 78. Expected mean site indexes in the Southern Appalachian Mountains are:

Chestnut oak	58
White oak	60
Scarlet oak	65
Black oak	68
Northern red oak	72

Humus of oak types is principally duff mull, except on the dry sites under Ericaceous shrubs where mor predominates. As the "maturity" of the humus layer advances from mor through duff mull to mull, depth of A_1 horizon also increases and thereby site index improves. Average site indexes are from 50 on the mor humus with no A_1 to almost 90 on the mull with a very deep A_1 layer (Doolittle, 1957) (Table 16).

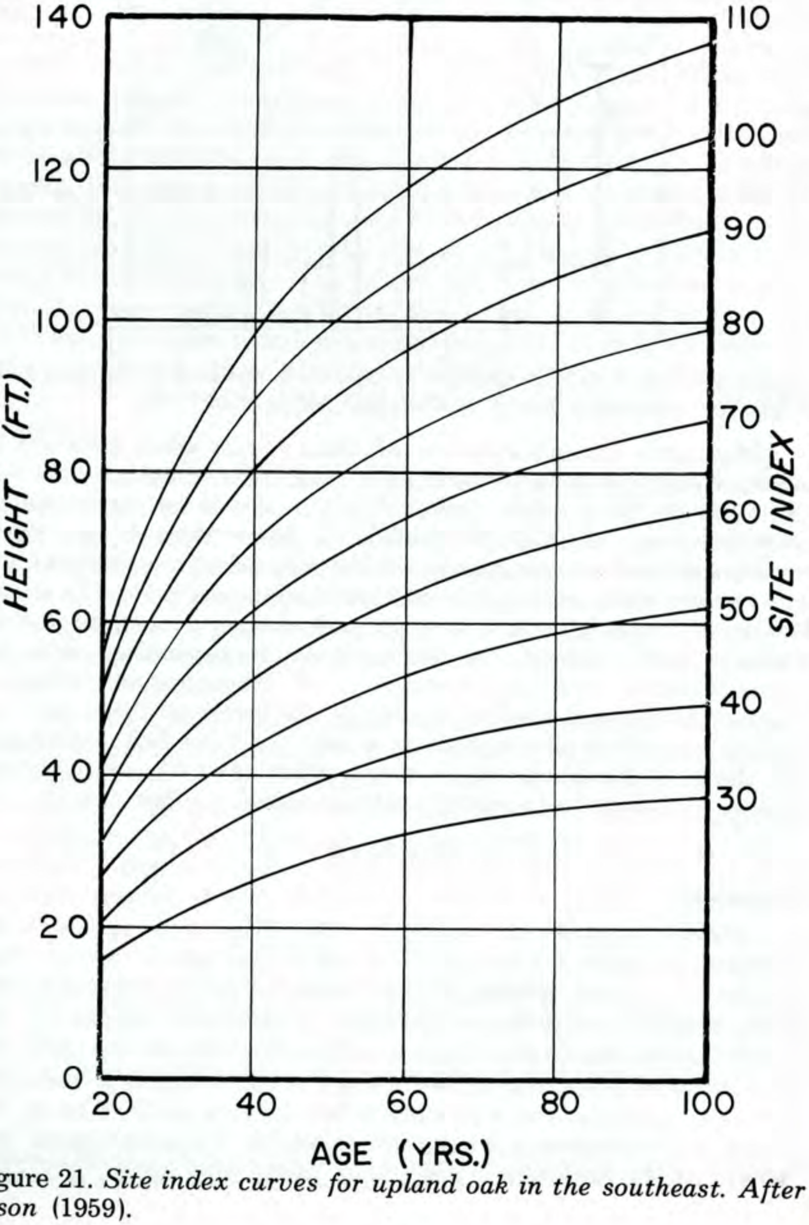

Figure 21. *Site index curves for upland oak in the southeast. After Olson* (1959).

Table 16. *Humus Types in Relation to Site Index of Scarlet and Black Oak* [*after Doolittle, 1957*].

Humus Type	Depth of A1	Average site index
Mors	None	50
Duff Mull	Shallow	58
Duff Mull	Deep	66
Mull	Deep	74
Mull	Very Deep	87

Drier slopes and ridges require surface soils perhaps twice as deep to have site productivity equivalent to that of moist slopes. If the *B* horizon is friable, surface soils can be several inches thinner and retain equivalent site potential. As depth of *A* horizon increases, so does the site index of scarlet and black oaks in the Southern Appalachians (Doolittle, 1957) (Fig. 22).

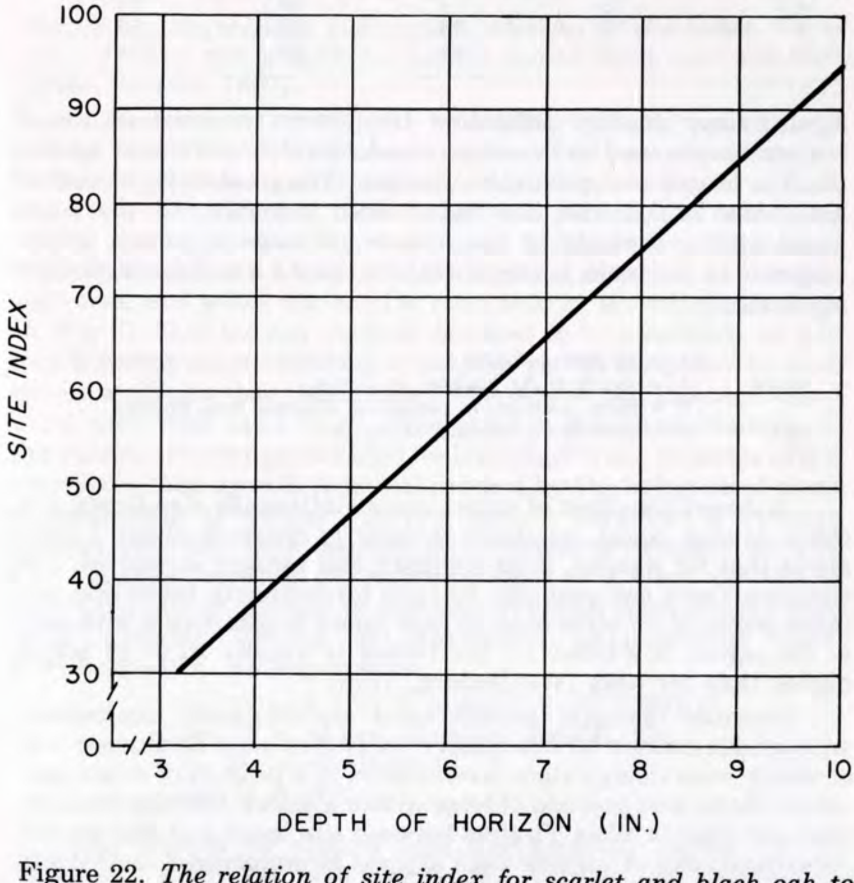

Figure 22. *The relation of site index for scarlet and black oak to depth of A horizon* [*after Doolittle, 1957*].

Site index is inversely related to position on slopes, but depth of the *A* horizon is also related to position on slopes. Nearer the bottom of a hill, depth of *A* and site index increases. A third variable, according to Doolittle (1957), is the percent of sand in the *A* horizon, to which site index is inversely related (Table 17).

Table 17. *Site Index of Scarlet and Black Oak by Percent of Sand and Depth of A Horizon for Middle Slope Positions [after Doolittle, 1957]*.

Depth of A horizon	percent of sand in A horizon			
	80	70	60	50
Inches				
3	26	30	35	40
4	35	39	44	49
5	43	48	53	57
6	52	57	61	66
7	61	66	70	75
8	70	74	79	84
9	79	83	88	93
10	87	92	97	101

Again, slope position influences the percent of sand in the *A* horizon—more sand on the ridges—and, therefore, percent of sand in the *A* is related to depth of that horizon. The greater the amount of sand, the less is the site index due, probably, to the lower water-holding capacity of coarse soils. Ninety-six percent of the variation in site index is attributable to these 3 variables, expressed algebraically:

$$SI = 38.7690 + 8.8057\,(A) + (-0.0477)\,(P) + (-0.4620)\,(S)$$

where A = depth of A_1 horizon, in inches,
P = slope position, in percent of distance from bottom,
and S = sand in A_1 horizon, in percent.

Although the effect of aspect is not statistically significant, site index on cool, moist, northerly to easterly slopes is about 7 units above that for warmer, drier southern and western exposures. The equation above can probably be used for indirectly predicting site index potential for other oaks. Where yellow-poplar occurs with oaks in the region, site index for the former is usually 10 to 15 points higher than for oaks (Wahlenberg, 1956).

Potential diameter growth rates are frequently conjectured without due concern for site quality, individual stem dominance, and stocking, even though vigor is recognized as a product of crown size, crown shape, and position of trees within a stand. Definite relations were obtained in West Virginia between site index and dbh growth for upland oaks of various vigor classes in unmanaged, unthinned, evenaged, well-stocked stands of immature trees (Fig. 23).

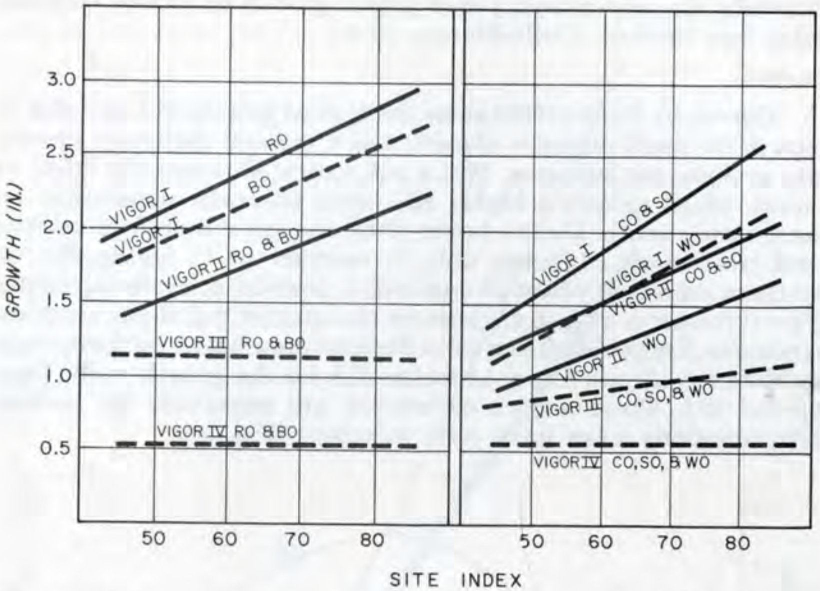

Figure 23. *Regressions and growth relations to site index. Curves show 10-year dbh growth* [*in inches, inside bark*] *over site index* [*after Trimble, 1960*].

This information (1) facilitates estimating growth potential on various sites, (2) aids in determining economic maturity diameters for individual stems, and (3) serves as a guide in marking. For SI 70 and Vigor Class I trees, diameter growth potential in descending order is red, black, chestnut, scarlet, and white oak. For Vigor Class II at SI 60, red and black oaks are superior, chestnut and scarlet oaks next, and white oak has the most inferior growth rate, and so on. For SI 70, if red oak vigor is assumed to be maximum, or 1.0; then from the chart, the relative position can be computed for each species and vigor class: black oak I = .9, scarlet and chestnut oaks I = .82, and white oak I = .67. Differences in growth attributable to site quality are more pronounced for high vigor trees, as stems of low vigor have their growth potential masked by the influence of many environmental as well as inherited factors. However, if thinning releases trees and they respond with increasing diameter growth, then thinning increases the apparent vigor of a stem. Growth of vigor I red oaks is affected by tree size, but other species failed to so react, possibly because of insufficient computational data. Mathematically, the response is:

$$G = 1.2373 + (0.0352)\,S - (0.0788)\,D$$

where G = 10-year diameter growth, i.b.,
S = site index,
and D = dbh.

Site indexes for upland oaks are generally higher for the Piedmont than for the Southern Appalachian Mountains. Nevertheless, yellow-poplar may be used as an index species.

Generally the oaks exceed yellow-poplar growth on locales with site index less than 81 (Della-Bianca, 1959).

Ozarks

Curves by Nash (1959) show the typical pattern of a fast rise in growth for small diameter classes, and a gradual decline in growth rate as diameter increases. White oak curves illustrate the effect of aspect, which reflects a higher site index on north slopes than on those facing south. On the better sites, the growth peak is delayed until trees reach 16 inches dbh, in contrast to 11 inches dbh on southern aspects. Even at 20 inches dbh, trees on north-facing slopes grow three times as fast as those on the warmer, but drier, southern exposures. Larger black oak trees likewise grow better on north- than south-facing slopes: 12 vs. 11 inches dbh for the growth peak (Figs. 24 and 25). These aspect differences are important for volume determinations when basal area is known (Fig. 26).

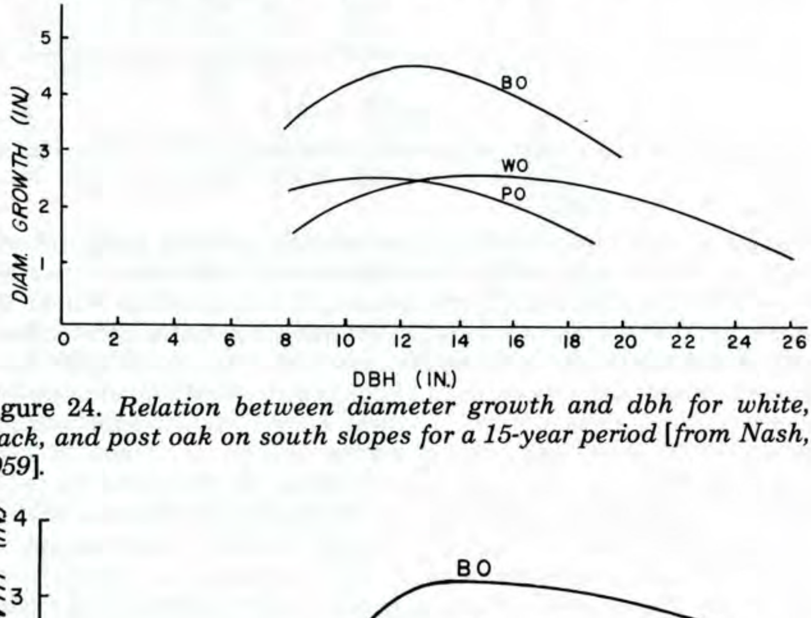

Figure 24. *Relation between diameter growth and dbh for white, black, and post oak on south slopes for a 15-year period [from Nash, 1959].*

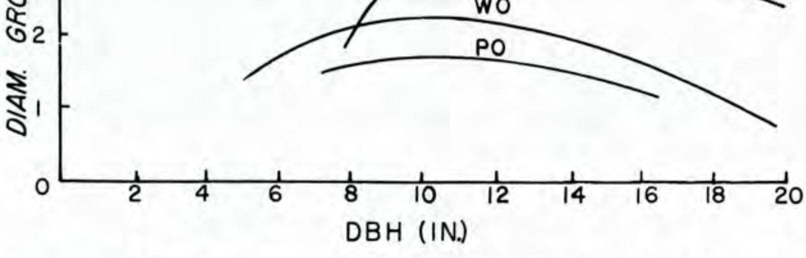

Figure 25. *The relation between diameter growth and dbh for white, black, and post oak on north slopes for a 15-year period [from Nash, 1959].*

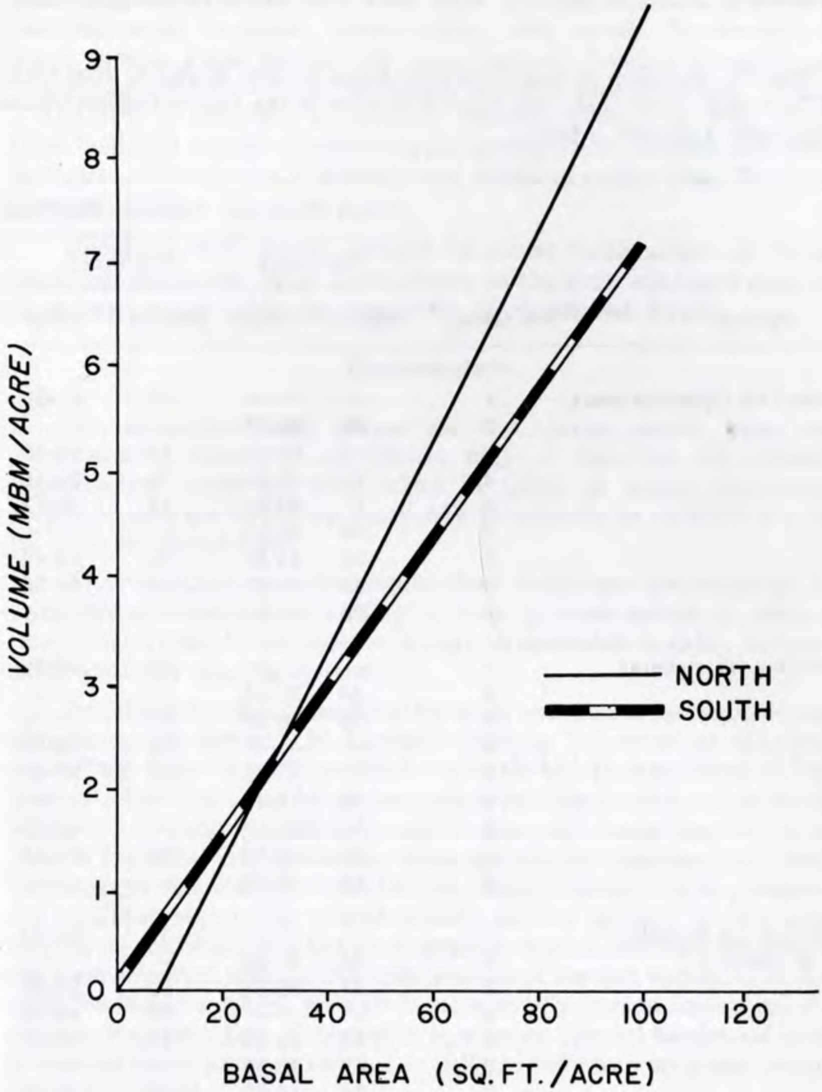

Figure 26. *The relation of oak basal area to volume, taken by prism or formula, for northern and southern slopes of the Ozark Mountains. Intermediate directions may be interpolated [from Nash, 1959].*

Low site potential is also associated with slowly permeable shallow soils, freely permeable deep soils, and rough stony land. Indexes are higher for deep soils, where there is little gravel, slopes are gradual, and opportunities for deep rooting in rock fractures occur.

Savannas, where soils are low in available moisture storage capacity and replenishment of water may be delayed for long periods during the early part of the growing season, are important in Ozark wildlands. Soil groups 1, 2, 3, 5, and 6 of Table 18 are generally

Table 18. *Relation of Soil Characteristics to Site Index of Red Oak, White Oak, Post Oak, and Shortleaf Pine in the Ozark Region* [*after Ray and Lawson, 1955*].

		Ozark Highlands		Ouachita Highlands	
		Site Index		Site Index	
Species	Soil Group [1]	Median	Range	Median	Range
White Oak (Quercus alba)	1	---	--------	27	21-35
	2	30	25-37	---	------
	3	---	--------	30	26-40
	4	32	27-44	35	25-45
	5	41	30-57	41	37-47
	6	39	32-52	---	--------
	7	50	43-58	49	49-42
	8	65	55-71	60	54-65
	9	72	67-78	---	--------
Post Oak (Q. stellata)	1	---	--------	26	20-36
	2	30	20-43	---	--------
	3	30	28-32	34	26-41
	4	---	--------	35	25-44
	5	37	29-48	40	39-41
	6	38	30-47	---	--------
	7	56	50-57	50	45-55
	8	65	50-76	60	50-69
	9	74	70-76	---	--------
Red Oak (Q. borealis, Q. falcata)	1	---	--------	37	24-30
	2	30	27-35	---	--------
	3	31	26-34	32	26-39
	4	---	--------	35	25-45
	5	42	32-53	45	43-47
	6	42	33-58	---	--------
	7	54	45-57	50	45-57
	8	63	56-72	58	53-66
	9	75	73-83	---	--------
Shortleaf Pine (Pinus Echinata)	1	---	--------	33	30-39
	2	32	30-33	---	--------
	3	36	27-37	40	35-50
	4	---	--------	---	--------
	5	45	43-65	50	44-56
	6	45	30-48	---	--------
	7	---	--------	54	38-67

[1] See descriptions, page

such savannas, and on these sites water storage depends on depth to bedrock, rock fractures, permeability, and runoff. Hardwoods in these groups grow slowly, are short-bodied, develop dieback, and frequently are hollow from rot before trees are merchantable. Groups 7, 8, and 9, in contrast, are usually forested, producing long, sound trees in closed stands of moderate to rapid growth. Grasses and forbs are scant. Group 4 is a transitional forest-savanna area (Ray and Lawson, 1955).

Corollary with better growth on moist north slopes is better stocking. No doubt, fires, more severe on the drier southern aspects, have been responsible for depletion of hardwood forests.

Regeneration

As abundant seed crops do not occur every year and simultaneous failure of all species may or may not be unlikely, reproduction must be established in years of acorn abundance. Reproduction not found by April will be unlikely as no seeds are left by then to germinate.

Five hundred to 1000 established seedlings are required for adequate stocking. As browsing by deer is more severe in years of poor acorn yields for all species, it may be desirable to delay harvests until years of abundant seed.

Prolific epicormic branching by oaks and hickories requires that dominants be favored in harvest cuttings in order to minimize degrading. Species such as black oaks should be harvested if high quality white oak is to be grown, since the black oaks out-grow the white oaks, making probable much epicormic branching on white oaks of the lower crown classes. Most growth for selection harvests is in the upper size classes while for the clearcut areas it is in groups of the smallest size trees. Uncut stands put on growth in the same classes as selection, but not to so great a degree. Growth differences between selection and flexible diameter limit are not appreciable, but with the latter method, growth is more evenly spread among all size classes. Reproduction of desirable species on upland hardwood areas protected for 20 years or more is usually satisfactory with any partial cutting method.

Southern Appalachians

Selection - Selection by groups is recommended for oak stands. It is the best technique for obtaining reproduction in decrepit stands, but is unfavorable for seedling and sapling growth due to competition of encroaching vegetation. About one-third of the basal area is removed in the initial cut and probably less at subsequent harvests in 15- to 25-year cycles. With selection cutting, quality of composition is improved, as the best of the larger trees are left, inferior stems among the smaller trees taken, and the release treatment extended uniformly over an area and over a wide range of tree sizes. Trees in the understory are favored more than those in the overstory.

Shelterwood - In the shelterwood system, since oaks are ecologically climax, they will not likely be replaced by inferior species other than hickory. Perhaps one-half of the stand is removed at the first cut, the balance in one or two harvests at 3- to 5-year intervals.

Seed-Tree - Seed-tree harvest methods are not recommended because acorns are not dispersed far and are consumed by rodents. Overhead canopy and litter are needed to reduce desiccation of acorns. Though oaks are ecologically climax, they may not replace themselves if harvested by the seed-tree method. If the method must be used for economic reasons, 10 to 20 trees per acre, amounting to between 1.5 and 2.5 MBM, are left to provide litter and shade as well as mast. These trees should be healthy-appearing, with well-developed spreading crowns, and at least 18 inches dbh (Wahlenberg, 1956). Leaving twice as many trees 12 to 16 inches dbh is preferable to leaving fewer larger trees. Seed trees must be well distributed for even dispersal of the heavy seeds.

Clear-cutting - Clear-cutting of mixed hardwood stands produces more basal area growth than either diameter limit or selection harvests, much of which is in sprout reproduction. About one-half of the shoots may be desirable species (Jemison, 1946; Wahlenberg, 1953), but species composition of clear-cut areas often remains unchanged from uncut areas 20 years later.

Diameter Limit - With diameter limit cutting, the number of trees removed is flexible. One-half of the 14-inch class and all of the 16-inch class may be cut, except for perhaps occasional seed trees above 16 inches. Although differences in growth do not justify diameter-limit cutting above other methods, the advantage is in the high quality of product presently harvested. However, because high quality logs show the greatest increase in value with added growth, diameter-limit cutting sacrifices financially immature stems. It also provides spotty overhead release for smaller trees and fails to release many in the understory.

Piedmont

Clear-cutting of chestnut oak second-growth in stands of about 60 square feet per acre basal area results in good regeneration, in contrast to that obtained by partial cutting and in the absence of cutting. Much reproduction is from seeds, but almost all trees larger than 1 inch dbh after 10 years originated from sprouts. Since, by that time, average height for about 800 stems per acre is more than 20 feet and the average dbh 5 inches (Knuenzel, 1942), only a few true seedlings will successfully be established among such rapid-growing stems.

Where desirable, the white oak-black oak-red oak type can be converted to pine by clear-cutting and planting or by making openings of ½ acre in which natural regeneration occurs. Mature pine from areas this size can in turn regenerate about 1½ acres of surrounding area. Thus, 5 to 6 clear-cut patches will suffice for conversion of a 10-acre tract, and may be preferable to clear-cutting and planting where conversion over a longer period at low cost is desired.

Ozarks

Seedlings are plentiful where sites are protected from fire and grazing but, even so, sprouting is the principal source of hardwood reproduction in the Ozarks and adjacent highlands. In a 15- to 30-year-old forest, the amount of reproduction attributed to sprouting was between 60 and 90 percent for oaks, hickories,and sassafras and about 35 percent for shortleaf pine (Liming and Johnston, 1944). Poor seedling regeneration is in part due to insect and disease attack upon seeds shortly after their dispersal. Kantz and Liming (1939) found one year's crop 98 percent defective, and only 200 sound acorns per acre under crowns of older trees. This would be a sufficient supply if it was maintained over a number of years and accompanied by high germination and seedling establishment.

Blackjack oak, of low marketable value, serves as a nurse crop or trainer for more valuable species. This species occurs in patches of less than 50 acres with about 300 stems per acre, half of which are blackjack oak, and one-third of which may be mature. The balance is shortleaf pine; white, black, and post oaks; and hickories. In such stands, natural improvement is rapid through high mortality of blackjack and post oaks. Moreover, blackjack oak makes up a smaller percentage of the reproduction of the overstory and its growth rate is slower than that of the more desirable species (Liming, 1942). It contributes little to site improvement. Mineral content of its foliage is only two-thirds that of other oaks in the region and, consequently, it is resistant to weathering decomposition (Kucera, 1959) and relatively unattractive to soil fauna. After valuable species are established, this scrub oak should be weeded. Stand improvement will double the basal area growth over a 17-year period which, except for ingrowth, is only about 25 feet.

Southern New Jersey

To convert coppice stands to high forest in southern New Jersey, Wood (1938) recommended this procedure:

(1) Prepare seed spots a year in advance of sowing by removing all competing vegetation and treating with insecticide to kill root-eating grubs.

(2) Apply lime to raise pH.

(3) Plant in each spot a few large, sound acorns in the horizontal position 1 to 2 inches deep.

(4) Mulch with sphagnum moss.

(5) Fertilize with a complete formulation.

(6) Protect with rodent-proof screen.

(7) Remove excessive mulch after germination.

(8) Remove protective screen.

(9) Control vegetative competition.

Seeds

Production - Seed production per unit of ground area under Southern Appalachian oaks was found unrelated to dbh, crown ratio, crown diameter, age, growth rate, and "maturity" class. But, within species, acorn production per unit of crown volume is approximately the same for all trees and therefore total acorn production is directly related to size of crown and indirectly to dbh. Dbh generally increases proportionately to an increase in crown volume (Downs and McQuilkin, 1944). Wood (1934) also found larger trees to be the most vigorous, and oldest trees to be more prolific than their opposites. Some trees may be heavy producers and others light due to microclimatic or inherited characteristics.

Year-to-year trends in acorn production follow a common pattern for all species; that is, white oak mast is abundant in the same years that black oak is good. This is particularly interesting since species members of the white oak sub-genus mature mast in 1 year while those of the black oak group require 2 years. It is noteworthy that acorn production was found similar for two mountain areas 150 miles apart, though with rainfall differing by 20 inches (Downs and McQuilkin, 1944; Wood, 1934).

Generally seed-fall begins in early September, peaks between mid-September and early November, and ends between mid-October and the first of December. Poorly developed acorns drop a month prior to the fall of well-formed seeds. Downs and McQuilken (1944) state that 20 to 60 percent of well-developed acorns are sound when dropped. Birds and squirrels destroy about one-fourth of the acorns on the tree, and insects may take another 30 percent. A typical seed tree in a good year may disperse 1300 sound seeds, only 100 of which will germinate.

Predators - Once on the ground, nut weevils (the worst offender), moth larvae, and gall-forming cynipids feed on mast during larvae stages. Thus, acorns are subject to serious insect damage through the time of germination and probably as long as any predator food remains in cotyledons. In the course of existence for 92 damaged seed which germinated in spite of injury, 16 survived. Apparently, if the plumule and radicle of embryos remain intact, even though cotyledons are almost consumed, some germination occurs and healthy seedlings are produced. Acorns, being large, have cotyledons which can withstand much damage and still provide adequate initial nutrient and carbohydrate supplies for seedlings.

Deer are known to consume entire mast crops in typical seed-producing years. After germination, the long-tailed wood mouse cuts chestnut oak seedling roots for food,and soil-burrowing rodents sever roots when they construct burrows.

It is sometimes stated that wildlife, particularly squirrels, prefer acorns of the white oak subgenus over those of the red oak group because the latter are cathartic. Christisen (1955) found no evidence to support this contention. Squirrels aid regeneration by burying acorns.

Seedbeds

Oaks germinate well in litter of moderate thickness—1 inch, but litter, which is too deep discourages valuable species. Thin litter, less than ¼ inch thick, on the other hand, encourages non-timber species. Hickory germination is better with thicker litter on drier sites than on more moist sites (Minckler and Jensen, 1959). Apparently under xeric conditions, the heavy mat aids in conserving moisture for use by tender seedlings. Litter depth can be partially controlled by logging disturbance and deliberate scarification.

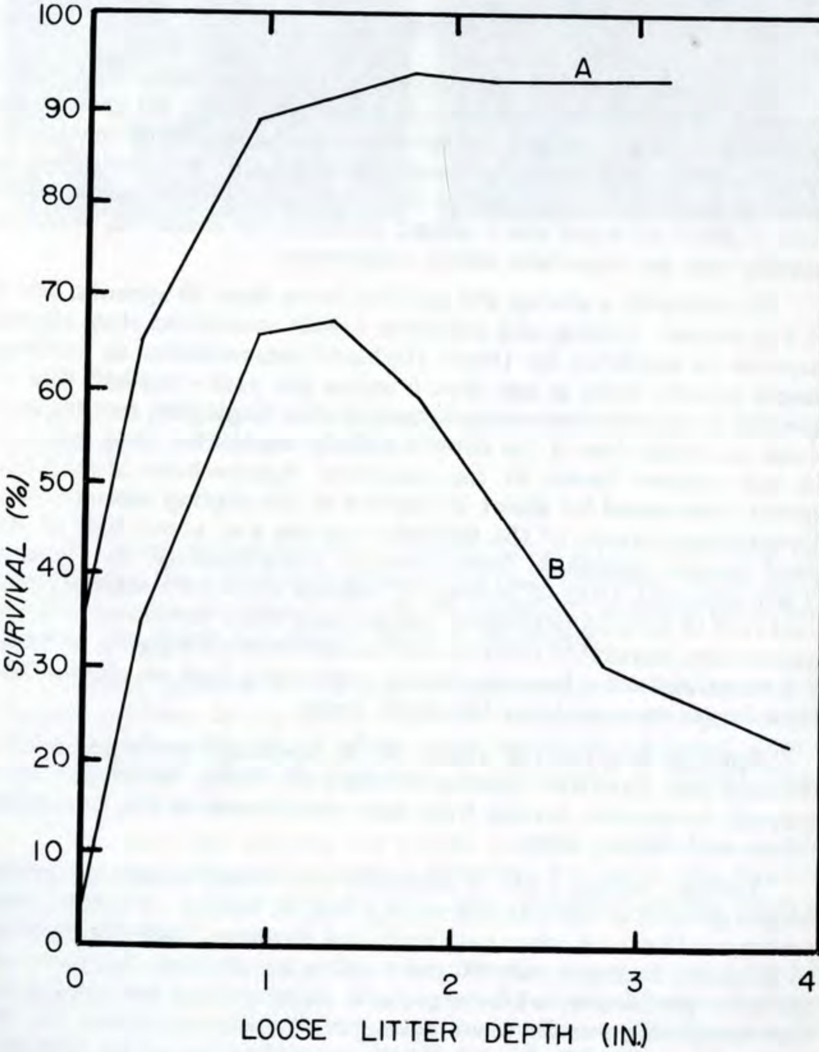

Figure 27. *Effect of leaf covering upon percent of acorns producing green seedlings by late July of first year after seedfall* [*after Barrett, 1931*].

For chestnut oak, especially, germination is best where litter cover is 1 inch deep. Slightly better germination of this species is obtained under some overhead shade and on moist northern and eastern slopes where there is little exposure to the sun's evaporating rays (Barrett, 1931) (Fig. 27). Germination of from 8,000 to almost 900,000 seedlings per acre has resulted, providing for well-stocked stands of second growth.

There is great danger of non-timber species occupying sites before reproduction can be established. To avoid this, undesirable advance reproduction should be destroyed, seedbeds prepared, or openings made which are large enough to promote growth of the more intolerant oaks and, perhaps, yellow-poplar.

Coppice

Many oak acres are reproduced by coppice sprouts, especially for short rotations, as for pulpwood, because trees do not grow to an age sufficient for adequate seed production. An initital advantage in height growth over seedlings is attained, but this is usually lost in about 6 years. Most sprouts of desirable species do outgrow weed trees if given an equal start except, perhaps, for sassafras, which is usually not an important stand component.

Occasionally a stump will produce more than 20 sprouts, but 6 to 8 is normal. Liming and Johnston (1942) considered stool shoots superior to seedlings for Ozark Highland regeneration, as seedling height growth there is less than 5 inches per year—one-half that of sprouts. Five generations may appear from a single root system, and these are rather free of the defects usually associated with sprouts. In one cutover forest of the Southern Appalachian Mountains, sprouts accounted for about 40 percent of the sapling reproduction. Twenty-two percent of the desirable species and about half of the weed species originated from sprouts. Unfortunately, as Hepting (1940) reported, 10 to 40 percent of coppice shoots are infected with butt rots of various pathogens transmitted from the parent stumps which were inoculated prior to harvesting through logging wounds, fire scars, and other injuries. Stems originating high on stumps and from larger stumps have the most decay.

Sprouts less than 5 years old in openings made by partial cuttings may have root systems 40 years old. Many "seedlings" may actually be sprouts, arising from buds on the stem at the root collar (Merz and Boyce, 1956).

Factors having little, if any, effect in stump sprouting or the height growth of sprouts are stump height, season of cutting, and presence of butt rot when cut (Roth and Hepting, 1943). Stumps up to 16 inches diameter and 100 years old in stands 50 to 150 years old sprouted prolifically, while larger and older stumps sprouted little. The break-off point for black oaks was 22 inches diameter, or 150 years of age (Fig 28). Keetch (1944) noted that sprouting increases with size of parent trees up to about 6 inches dbh and then decreases.

Figure 28. *Types of oak sprouts and a case of subsequent decay [from Roth and Hepting, 1943].*

Old trees apparently do not sprout because buds die of old age. In addition, thick bark may insulate the buds from heat which serves as a triggering mechanism for sprout emergence and also provides a barrier too tough for tender buds to penetrate.

Height growth of sprouts is apparently not influenced by rainfall patterns to any great degree, as height increment is usually completed in early spring when water supply is adequate, even in drought years. There is, therefore, a uniformity of sprout height growth for various sites.

For most oak species, the height of sprout origination on the stump is not influenced by stump diameter. For black oak, however, sprouts arise at higher levels on larger diameter stumps than on smaller stumps.

Many oak sprouts, unlike other broadleaf species, have sprouts originating below ground. Perhaps 30 percent of the dominant sprouts persisting for 5 years so originate. Such trees are distinguished from true seedlings with difficulty.

Methods - To obtain favorable coppice reproduction, stems for crop trees should be favored which originate from low, small stumps.

Control of sprouting is partially obtained by piling slash 18 inches deep on stumps. (Slash piled in excess of 2 feet deep does not further reduce sprouting, but those shoots which do appear may grow laterally along the ground surface to the edge of the slash pile and then turn upward (Joranson and Kuenzel, 1940). Trees cut after midsummer are not likely to sprout until the following growing season and hence may be shaded out in light cuttings.

Stems originating low are generally fire-caused, as heat kills buds higher up the trunk. Although a single prescribed fire after harvests aids in securing sprouts of low origin and in obtaining uniform reproduction, continued protection is then essential. Burns in the Ozarks have resulted in a high percentage of stool sprouts, so called because when tops are repeatedly killed, bark and subsequent sprouts develop enlarged, distorted, callus-like structures at the ground line. Tap roots surmounted by such structures resemble a one-legged milk stool.

Stand Improvement

In stands of medium vigor, as indicated by initiation of suppression, and in areas with undesirable stems taller than crop trees, one to two weedings, depending on differences in heights, are needed for white oak. Trees in stands of poor vigor, where overtopping has been of long duration and where there exists a great difference in height between crop and weed trees, should be released only when the overstory is worthless and several seedings financially feasible to bring the understory through.

The crop-tree method for timber stand improvement is based on the assumption that chestnut and white oaks 5 and 15 feet tall, respectively, are able to keep ahead of competing trees after release. Where selected crop trees are shorter, a second release after 5 to 10 years may be needed (Buell, 1940).

Coppice Stands

Companion sprouts larger than 3 inches at the base should be cut even though as many as 20 percent will have butt rot which has entered through stubs. After 5 years, only one-fourth of the smallest wounds, those less than 2½ inches, and practically no larger ones will have closed (Roth and Hepting,1943). Most wounds will be larger a year after cutting than at time of severing, even though flush cuts are made. Four years are usually required for 6-inch wounds to heal. It may be beneficial to wait until sprouts are 8 to 15 years old, as wounds made in cutting smaller stems are effective sources of fungi entry. Highest origin sprouts should be cut, as these become dominant and will also have the most rot.

Girdling companion sprouts is not too successful. While one-half may die back to the crotch, the balance will remain alive or bear lateral shoots which interfere with growth of the favored sprouts.

Dominance of coppice stands is generally expressed within 8 years, by which time the number of sprouts may dwindle to 3000 per acre with the tallest sprout per clump averaging more than 10 feet (Keetch, 1944). Often, after 5 years, the number of sprouts per clump is reduced to 1 to 3, at which time the cost of severing all but one is at its lowest point and the decision as to which to retain is easiest to make. Removal of all but one sprout will not stimulate growth of the residual in the clump (Buell, 1940). As there is little relation between rate of mortality and stump diameter or stump age, sprouts from large stumps are as persistent as those from small ones. Heights of sprouts at 5 years vary by species:

White oak	11 feet
Scarlet oak	12 feet
Black oak	13 feet
Red oak	14 feet
Chestnut oak	15 feet

Improvement of stands more than 20 years old is difficult, as one cannot tell which trees are already infected; and cutting some sprouts in clumps without creating a decay hazard is improbable.

Ozark Highlands - Unthinned stands and those requiring cleaning may not appear crowded, particularly in the stony dry soils of upper southwestern slopes of the Ozarks; but in one case, where only 27 square feet of basal area was left—and it not overtopping valuable species—growth was only one-fourth that of completely released stands. Complete release, therefore, and not just removal of overtopping trees is necessary. Spacing of about 17x17 feet is recommended and obtained by liberation and cleaning cuts in cherty soils of ridges and upper slopes (Read, 1951; Shoulders, 1956). Clark and Liming (1957) note that basal areas should not exceed 90 square feet for maximum growth.

On the better sites, those facing north and east and with deep soil, good hardwoods should be liberated. Removing the undesirable overstory is more effective than cleaning around selected understory crop trees as such understory stems generally sprout vigorously. Annual growth of desirable species due to treatment will probably be about ½ square foot basal area per acre or 35 board feet more than for untreated stands (Fig. 29).

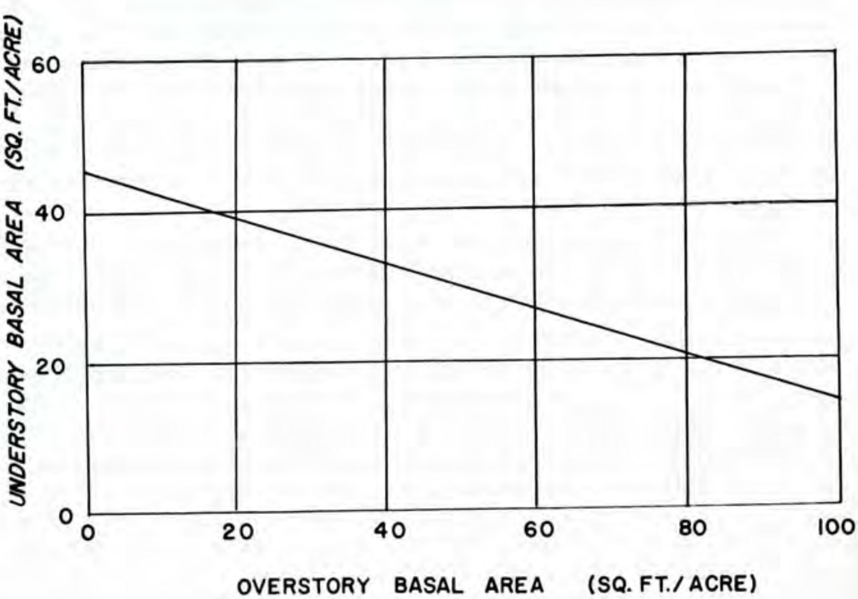

Figure 29. *Relation of total understory basal area per acre to total overstory basal area in pine and hardwood types in Arkansas [from Shoulders, 1956].*

Thinning

Basal area of upland oak stands serves to guide thinning operations (Table 19). White oak sapling stands should not be

Table 19. *Upland Oaks Thinning Guide. Basal Areas Include All Trees 0.6 Inches D.B.H. and Over* [*after Morriss, 1958*].

	Leave Basal Area (Sq. Ft.) for Site Index--				
Age	40	50	60	70	80
20	36	40	41	43	44
25	41	44	47	48	50
30	45	48	50	53	54
35	47	50	53	55	57
40	49	53	56	58	59
45	51	55	58	60	62
50	53	57	60	62	64
55	55	59	62	65	67
60	58	61	65	67	69
65	59	64	67	70	72
70	61	66	69	72	74
75	63	68	71	74	77
80	65	70	74	77	79
85	67	72	76	79	82
90	69	74	78	82	84
95	71	76	80	83	86
100	73	79	83	86	89

thinned, as the response to release is only fair. In pole size stands, however, thinning heavy from below is recommended to get a fair growth response and to salvage trees most likely to be lost. Thinning from above permits a response from present codominants and intermediates which are designated future crop trees, in which case residual stems must be of medium vigor or better. Even then, subsequent growth may not be as good as for thinning from below (Downs, 1946).

Coppice Stands - Coppice stands should be thinned by favoring stems of low origin, 8 to 15 years of age, at which time heights of origin are discernible. It is most effective before crowns close and for stems less than 5 inches dbh. Low-forked trees should be harvested, as later losses in wood volume may exceed 8 percent from high stumps due to forks (Downs, 1947).

In an evenaged 25-year-old white oak stand of sprout origin, thinning the clump to the best formed stem increased diameter growth two-fold if one stem was not dominant. Where one stem was dominant before thinning, its response was less (Table 20).

Table 20. *Six-Year Growth of Treated and Untreated Stems [from Gruschow, 1955].*

	6-year d.b.h. growth	6-year height growth
	Inches	Feet
Clumps with equal-sized stems		
Check	0.55	4.0
Treated	1.08	3.9
Clumps with unequal-sized stems		
Check	.64	3.9
Treated	.92	3.9

Height growth is not affected by sprout thinning (Gruschow, 1955). Five-year dbh growth of 1.2 inches was reduced by half after 20 years without additional thinning.

Low forking of white oak sprouts may be hereditary, according to Downs (1949). Environment also may be important in determining if sprout growth is excurrent or deliquescent.

Trees to retain in thinning should be (1) desirable species, (2) straight stems, free of defect, (3) trees without a tendency to wolf, (4) those with good vigor so that response to release will be favorable, and (5) seedling sprouts of low origin only. Suppressed sprouts and those originating from other than the bases of stumps are not retained because of the high risk of fungus entry. Good spacing of crop trees 2 to 5 inches dbh is about 11x11 feet, providing 400 stems per acre.

Epicormic Branching

A serious problem with oak forests, particularly evenaged undisturbed white oak stands, is epicormic branching after thinning which degrades high quality butt logs. Krajicek (1959) found the number and locations related to crown class; dominants in thinned and unthinned stands having fewer epicormic branches than other classes.

All sprouting is not related to thinning. For instance, in a 95-year-old unthinned stand, dominant trees had about 3 sprouts on the butt log, codominants 7, intermediates 7½, and suppressed trees 10. Dominant trees also had the most trunk faces free of sprouting and the greatest distance to the bottommost epicormic branch. Assuming a stand is evenaged, slow-growing trees are more apt to produce epicormic shoots than more vigorous stems. A few more branches may occur on the warmer southern to southwestern faces where the sun's heat may catalyze bud elongation, but generally the number of faces containing sprouts as well as the height to the first sprout is a simple function of the total number of sprouts; that is, the more sprouts, the more likely they are to be found on all faces. There is no sure evidence for the oaks that opening a single face increases sprouting on that face alone, but Krajicek observes that branches are larger on an open face.

Jemison and Schumacher (1948) found the number of epicormic branches to vary with species, site, merchantable height,and log position in the tree; and not to vary with volume before cutting. Most branches before cutting were on the top logs of 3-log hickories on dry sites and the least number for butt logs of 3-log northern red oaks on moist sites. Chestnut oak is also a prolific sprouter. Top logs and tall trees had the most branches.

As a result of cutting, almost one-half of the residual logs tallied by Jemison and Schumacher had more branches 7 years afterward than at time of logging. After cutting, the number of epicormic sprouts depends on original stand volume and volume cut, as well as upon merchantable height and log position. Site may or may not be a factor. Increase in shoot occurrence is greatest in stands with the heaviest volume before cutting and for those with the most volume cut. While hickories have may branches before partial cuts are made, they do not seem to have the response to release that occurs for oaks.

It may be necessary to leave shade over slow-growing crop trees to hold epicormic sprouting in check (Buell, 1940).

Pruning

Upland southern red oak stands may be pruned to 16 feet to improve wood quality. Trees should be about 6 inches dbh, and growing more than 0.2 inch per year in diameter. Larger trees have branches too stout for convenient removal, and stems with slower growth heal too slowly. Pruning large and slow growing branches increases the possibilities of decay entrance. Grano (1957) reports that 85 percent of red oak wounds are healed within 5 years and that only the incipient decay in dead branch stubs are sources of stem rot after pruning. Limbs free of decay at time of treatment will remain so.

Integrated Management

Range [Ozarks]

Much of the Ozark Highlands has long been grazed. Meadows and park-like forests were reported as indicators of good grazing 150 years ago—or, perhaps, the deer were hungry.

Little bluestem is the most important range grass, but forbs are the most abundant forage. Little bluestem is more shade-tolerant than broomsedge, yet is a comparatively weak and slow invader. Small openings produce 450 pounds of herbage per acre per year in contrast to 12 pounds in fully stocked oak stands. Thus if beef production is to be integrated with timber management, frequent harvests and control of undesirable overstory trees are necessary to increase perennial grasses and decrease forbs. In small openings, forage increase is probably more valuable for deer than for cattle (Martin, Dunkeson, and Baskett, 1955).

Exclusion of livestock and deer may be necessary on over-grazed ranges. Relief from heavy use for three growing seasons yielded about 850 pounds per acre, twice that of grazed areas. Although much of this increase was in non-preferred shrubs and vines, it need not be so as it depends to a degree on overstory density. Dense canopies also allow fewer shrubs to invade for deer food. A few years of exclusion to browse animals enable trees to get above the browse line, but forage then becomes scarce (SFES, 1959) (See Figure 30, page 90).

Generally, grazing capacity in upland hardwood types is between 20 and 30 acres for a cow for 6 months. Here the principal range plants are little bluestem and native legumes, both of which grow well in open woods, but produce little forage in well-stocked hardwood stands. Grazing should be discouraged as browsing and range fires destroy trees, and watershed values are reduced (Campbell, 1951).

Figure 30. *This Ozark forest of white oak, black oak, hickory, and winged elm had a definite browse line [top].*

After 10 *years of light use there was more low vegetation, but browse was sparce because most trees were out of reach of deer [bottom] [from Halls and Crawford, 1960].* (USFS Photo).

Watershed [Ozarks]

The best use for much of the broadleaf species' area of the Ozarks is for watershed protection. In areas so designated, burning and site preparation which removes litter should be prohibited as infiltration rates nearly double where these practices are excluded for 5 years. Even so, under mixed upland oak types growing in silt loams, infiltration rates are only a little more than 2 inches per hour (Arend, 1941). Mechanical litter removal, especially with heavy machinery, is more damaging than fire: soil channels through which water enters the soil are disturbed, the exposed mineral soil is altered by the beating action of rain which seals pores, and microbial and macrofauna activity is altered.

For improvement of the humus layer, American elm, sugar maple and hickories should be favored over the oaks. As the former group have the highest mineral content in autumn foliage (Kucera, 1959), they are least resistant to weathering, rapidly decompose each year, and are readily incorporated into the mineral soil. This provides improved soil structure which is beneficial for water absorption and storage, particularly in thin, cherty, limestone soils on steep slopes.

Shelterbelt [Ozarks]

Black locust has been planted in the Ozarks in shelterbelts with significant increases in cotton yields on the leeward sides. Strong southwesterly winds in spring blow loamy sand into piles 2 to 3 feet deep along fences, riddling leaves of cotton and corn. Shulley (1945) outlines the technique as follows:

(1) Plant black locusts every 4 feet in single rows on southern and western sides of a 40-acre block.

(2) Plant one row of black locust through the middle of a "forty" in an east-west direction. Plant in furrows and tamp tight.

(3) Cultivate the locust in the first and second years.

(4) Replace dead trees.

(5) Plant row crops in and east-west direction.

(6) Plant alternate strips of close-growing grains and vetch in east-west directions.

The black locust will be about 30 feet tall and up to 10 inches in diameter in 5 years.

Diseases

Top Rots

External indications of decay can be employed for determining average volume of cull due to top rot in oaks, with five risk classes relating the volume of cull to be expected (Fig. 31):

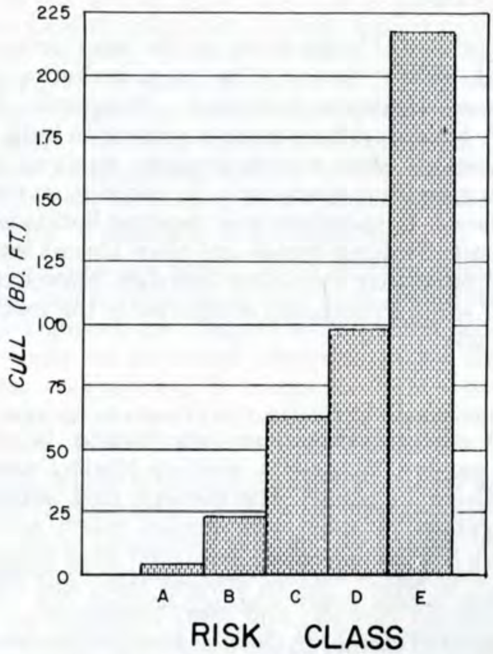

Figure 31. *Average volume of cull due to top rot in oaks according to five classes of risk based upon external indications of decay* [*see text*] [*from Hepting, Garren, and Warlick, 1940*].

A. No rot in stubs over 3 inches thick, no large surface wounds, no holes, and less than 3 blind knots or healed stubs anywhere on the bole up to 8 feet above merchantable top.

B. One rotten stub or large surface wound, or 3 blind knots.

C. Two rotten stubs or large surface wounds, or 4 to 5 blind knots and stubs.

D. Three rotten stubs or large surface wounds, or 6 to 7 blind knots or stubs.

E. Four rotten stubs and wounds, or 8 or more blind knots and stubs.

Any tree with the top out, a hole in the bole, or with a conk is likely to be a cull, but conks on living oaks are rare. Heart rot fungi of importance are *Stereum frustulosum, Hydnum erinaceus,* *Polyporus sulphureus, P. berkeleyi, P. hispidus, Stereum gausapatum*, and *Poria spiculosa* (Roth, 1959). These are discussed elsewhere.

Most *Strumella* cankers occur in the lower 8 feet of stems, rendering the butt log worthless. Trees with such infections should be removed early in the life of the stand, as infection generally occurs before trees are 20 to 25 years of age, regardless of vigor (Bidwell and Bramble, 1934).

Butt rots

Butt rots at the base of living trees are the most serious cause of cull in southern oak-hickory forests. The fungi, including principally *Pleurotus ostreatus, Hydnum erinaceus, Polyporus fissilis, P. sulphureus,* and *P. lucidus,* enter through wounds in bark. About 80 percent of the infections start at fire wounds, most of the rest at injuries made during logging operations. In addition to visible rot in open wounds, hollows, butt bulges and fruiting bodies are reliable indicators of butt rot. Fruiting bodies are often absent because they may not be formed until after a diseases tree dies. Spores of these rot fungi are borne by wind. Prevention of injuries is the most practical control (Toole, 1960).

Oak Wilt

The oak wilt disease threatens oak forests in the region. It is spreading in eastern Tennessee, western North Carolina, West Virginia, and northern Arkansas. The malady, first detected in the Southern Appalachians in 1951, was known much earlier in the mid-West and Lake States. Although scattered local centers appear, averaging 0.4 acre, in which one to several trees are affected, the disease does not spread rapidly, and local transmission usually is within 50 feet of infected stems. In the northern portion of the region, most oak wilt occurs on ridges and upper slopes of sandstone outcrops never logged. Relatively little infection occurs on high quality soils of limestone or alluvial origin (Craighead and Nelson, 1960). Because high temperatures and low humidity appear to limit fungus growth and sporulation, as the pathogen will not survive in twigs more than 3 days at temperatures of 90 degrees F, it has been predicted that the wilt may never be serious in warmer sections of the South (Toole and Morris, 1956).

Root grafts may serve as principal pathways of local infection, since oaks are commonly root-grafted inter-specifically. Yet very few infected trees have root grafts, although they are within the root zones of trees previously killed by oak wilt (SEFES, 1959). It is also possible that spread is the result of contaminated sap-feeding beetles carrying spores from the dense, scattered mycelial mats to fresh wounds of healthy trees (Boyce, 1959). Flies, bark and wood borers, such as the two-lined chestnut borer which mines below the cambium into 1 or 2 annual rings, pileated woodpeckers which are restricted to areas of old defective timber at times when oak wilt is prevalent, or squirrels which strip bark from over fungus mats may carry the inoculum, but this has not been confirmed. Pressure of the mycelial mats against the bark cracks and splits it, exposing the mats to insects, birds, and rodents. The hypothesis that a metabolic toxin is produced by the oak wilt pathogen, causing wilting and death of leaves (White, 1955), is unconfirmed.

Symptoms - All species of oaks are susceptible. Early symptoms of the disease for the red oak subgenus are bronzing and wilting of foliage, beginning at the ends of branches in the upper crown, within 2 to 3 weeks of inoculation, and extending downward until the entire tree is affected. Death occurs in 1 to 2 months after the onset of symptoms. Leaf discoloration usually begins at the tips and lobes of leaves and extends inward toward main veins and mid-ribs. Shedding of green and discolored leaves during the growing season is an important diagnostic feature. Sprouting then occurs on the trunk and main stem, but these shoots are short-lived. Cuts into the trunk reveal black longitudinal streaks in the sapwood, while vascular discoloration may be seen in twigs (Roth, 1958, 1960; Kuntz, 1954). A fruity odor is typically symptomatic.

For the white oak group, there is more gradual development of the disease, and several years may pass before death occurs. Vessel cells of the sapwood are clogged with tyloses. Wilting and bronzing take place only on scattered branches, rather than over the whole crown, and stagheading is frequent. New wood laid down over infected rings often results in temporary disappearance of symptoms (Kuntz, 1954; Roth, 1960; Fowler, 1958).

Control - There is no sure control or cure for oak wilt disease, but one or more of the following ideas may be at least partially effective. Overland spread is reduced, but not controlled, with summer felling and spraying of wilted oaks using a mixture of fungicide and insecticide: 0.5 percent gamma BHC and 2 percent penatchlorophenol in No. 2 diesel oil (Boyce, 1957). Another treatment is to cut all diseased and healthy oaks within possible root graft distance (50 feet) and then poison stumps.

Ammate, once recommended for treating stumps, is not toxic to the fungus, does not kill roots too well unless applied before trees develop 50 percent wilt, and treatment with this salt will injure many healthy trees (Craighead and Nelson, 1960). There is a possibility that methyl bromide pumped into the soil at depths of 26 to 30 inches will kill grafted roots.

Sodium arsenite in strong alkaline solutions has also been used, treating all trees within 25 to 50 feet of recently infected stems, and further out for earlier infections. It should be used in a continuous frill close to the ground (Riker, 1957). While the procedure is questionable, no sprouting will occur, roots will be killed, and, except for Ambrosia beetles, insects will not feed on the wood. Cattle and game, however, will be attracted to the salty-tasting arsenic (Craighead and Nelson, 1960).

Diseased trees alone may be treated and the healthy stems left standing and periodically examined to see if the disease remains active. Removal of bark from infected trees after cutting is also recommended to prevent formation of fungus mats.

Wounds made by pruning in oak-wilt areas should be done between the times that buds and leaves mature (Riker, 1957).

Until further confirmed, increment hammers should not be used in oak wilt areas, as trees wilted when contaminated insects were placed in increment hammer wounds. Similarly, bleeding wound pockets, holes that penetrate xylem of infected trees, stumps which exude sap for weeks, ax cuts, insect holes, and any other cavity that fills with water may be a culture medium for inoculum during humid weather when such injuries hold water. Fresh wounds, immediately attractive to insects, lose the palatability after a day, but regain attractiveness if again bled by bacterial or yeast action (Craighead and Nelson, 1960).

BLACK LOCUST

Much enthusiasm for the potential of black locust for erosion control and rapid reforestation prevailed during the 1930's and early 1940's. However, with experience it was noted that, after all, a good cover crop is not always produced. Nevertheless, the possibility of renewed interest in black locust for particular problem sites prompts its treatment here.

Foliar and Soil Relationships

From age 20 to 35, production of black locust leaf matter is rather constant, amounting to about ten thousand pounds per acre of litter. The humus layer formed by this litter develops several years sooner than it does under pines, perhaps because leaf fall begins the first autumn after plantation establishment.

Black locust may not cause a significant accumulation of nitrogen in the upper mineral soil, although rapid decomposition liberated about 60 pounds per acre of nitrogen per year under closed stands (Auten, 1945). This nitrogen, as soluble nitrates, is used promptly by plants or lost in drainage water: it is not stored. By comparison, Ike and Stone (1958) found total nitrogen increases of approximately 600 pounds per acre at the 0- to 20-inch soil depth, where nodules were present. Including the amount of nitrogen added by foliage and twigs, the total annual return to the soil surface from the biomass is estimated at more than 50 pounds per acre, apart from nodule contributions. This is considerably above that of other forest types.

Where catalpa grew with black locust, nitrogen in the soil under catalpa was about 10 percent less than under the legume (0.10 vs. 0.09) (Ferguson, 1922).

Phosphorus, potassium, and pH of the soil are not affected by black locust (Ike and Stone, 1958). Ike and Stone (1958) observed no changes in soil porosity as a result of black locust introduction which contrasts with Auten's findings of improvement in soil structure.

Species Relationships - Ike and Stone (1958) and Auten (1945) found black locust to stimulate growth of associated species. Allard (1943) reported that in Virginia, yellow-poplar, oaks, and hickories come in under black locust, the former overtaking the latter. Yet locust is not found in nearby stands of Virginia pine in spite of the fact that, like Virginia pine, it occurs in burns and barren ridges as a constituent in early stages of succession.

Black locust foliage decomposes readily, but may not become promptly incorporated into the mineral soil. Thus, soils with surface layers more like those of prairies than forests develop. The sod which forms has slow infiltration capacity and, while erosion may be prevented on micro-sites, runoff to slightly lower elevations may be appreciable. Sod does not always result. In Virginia, it appears that the leaf litter of black locust excludes old-field grasses—broomsedge, purple top, and Indian grass in favor of dense honeysuckle vines and herbs. Sparse foliage of the canopy might afford illumination beneath crowns, inducive to herb encroachment on nitrogen enriched soil. In the upper Piedmont it was reported by Bruner (1941) that native pines serve better than black locust for erosion control on galled slopes. Bruner (1955) later reported that 17 years after planting, loblolly pines had far exceeded the growth of locust trees where the two species were planted in alternate bands.

Sites

Black locust grows best on alkaline, well-drained, loamy soils. It should not be planted in sandy, very acid, or poorly-drained sites, the latter evidenced by compact, plastic subsoil near the surface, or grayish or bluish-gray mottled subsoil. Bedrock within 24 inches results in perched water tables and, therefore, poor drainage. Auten (1945) did obtain satisfactory growth where pH was as low as 4.6, but confirmed that limestone-derived soils, even if acidic, are best. Good growth was also observed in well-drained "sweet" soils of the Mississippi River Delta (Mattoon, 1930). Greater foliation of trees occurs in aerated than in compact soil (Coile and Gaiser, 1942).

Depth to compact layers of sandy clay or clay in eroded soils of sandy loam and fine sandy loam in north Mississippi indicate the height growth potential of black locust. Where the surface horizon is absent, trees grow about 2 feet in height the first 4 years. Then, with each 2-inch increase in surface soil depth, height growth increases about ½ foot in the 4-year period. Trees planted in surface soils 1 foot deep average 5 feet in height in 4 years: where the top soil is 2 feet deep, growth is about 8 feet (Roberts, 1939). Minckler (1941a) recommends against planting this species in old-fields.

Best black locust growth is related to light quality. However, the silvicultural implication is not clear, unless to suggest canopy types which black locust might tolerate. Trees are succulent and have twice their normal growth under red rays, in spite of the chlorotic condition of the foliage (Phillips, 1941).

Fertilization

Liming, fertilization, and cultivation improve growth, even on better sites. Excellent survival and growth have been obtained with 1 tablespoon of a 2-12-6 formulation placed in the planting hole. Diameters 1 inch above the root collar were an inch larger and heights 5 feet greater at age 4 for fertilized than for untreated trees. More fertilizer did not improve growth, but less reduced it. Root burning did not occur, probably because of the relatively little amount of nitrogen and potash salts in this formulation (Den Uyl, 1944). Root burning also was not apparent when 4 ounces of 4-12-4 were applied at a depth of 6 inches in planting holes in a shaly silt loam soil on gullied slopes. The treatment doubled height growth the first year even though weed competition was stimulated (Holsoe, 1941).

In greenhouse pot studies with an infertile plastic clay of the upper *C* soil horizon, at a pH 4.3, phosphorus fertilizer alone stimulated growth (McComb and Kapel, 1942). The use of supplements of this element, perhaps in the form of colloidal phosphate on badly eroded sites, accompanied by liming is, therefore, a prescription worthy of consideration.

Honeylocust fertilization with triple super-phosphate and potash, applied at 5 year intervals, accelerated growth by 1½ feet in height and 1 inch dbh after 3 treatments (Zarger and Lutz, 1961).

Cultivation

Two months after cultivation of young trees in Mississippi loess soils, the number of leaflets, total area of leaflets, and length of terminal shoots was greatly enchanced (Meginnis, 1934) (Table 21).

Table 21. *Comparative Leaf Production and Terminal Growth of Cultivated and Untreated Young Black Locust 55 Days After a Single Cultivation* [*average of 25 trees*] [*after Meginnis, 1934*].

Total number of leaflets		Total area of leaflets		New growth: total length of the terminal shoots	
Cultivated	Not Cultivated	Cultivated	Not Cultivated	Cultivated	Not Cultivated
1.481	717	980	232	12.7	3.1

Both the number of leaflets and their total area are indicators of the amount of photosynthetic tissues available for the production of carbohydrates and, hence, growth improvement. Foliage was retained 3 weeks later in the autumn than was the case for untreated trees. Cultivated trees also survived better by 17 percent.

For some unexplained reason, leaf miners seem to prefer weakened trees to the greener, more succulent, nutritious tissues of cultivated stems.

Genetics

The distinctive growth forms of black locust—from pinnate to palmate—and the rate of growth are probably inherited characteristics (Hopp, 1941). Heavy light-colored plump seed produced superior seedlings in the Tennessee Valley (Cummings, 1947). For nursery production seeds of this description should be collected from fast-growing, straight-formed young trees.

Pruning

Black locust is pruned only to reduce the effect of top-damage or to improve seedling form. It is possible that mortality is increased and growth reduced. Plant food is stored in stem tissues—xylem, medullary rays, and sometimes even the pith—and these carbohydrates are lost in pruning (Meginnis, 1940). Under some conditions, growth of terminal shoots may be stimulated by pruning, but none other, as new growth is concentrated at relatively few growing points. The influence upon the terminals is probably of short duration.

Injurious Agents

Insects

Locust borers completely riddle the wood of stems, making holes the size of a lemon, and making stems unmerchantable even for fence posts. Infestation, usually occurring after the bark roughens, does not generally girdle or kill trees. Craighead (1937) found borer injury following a 6-week drought apparently killed trees. Den Uyl (1944) and Berry (1945) believe that factors which stimulate growth tend to reduce susceptibility to borer injury, but observations by the writer do not substantiate this contention. Vigorous trees, fertilized and watered, are severely attacked even when separated from other black locusts by hundreds of yards. Slow-growing trees seldom overcome the effects of heavy attack, in contrast to the rapid recovery of physiologically healthy stems. Trees less than 5 inches are most susceptible to attack and injury. Thicker bark protects larger ones.

Planting black locust in mixtures with other species and regenerating stands by coppicing do not lessen borer injury (Berry, 1945). Shipmast locust, a tall, straight-growing variety of the species, is equal to other strains in susceptibility to attack.

A locust twig borer damages trees in the sapling stage. It does not reduce survival or growth appreciably (Williston and Huckenpahler, 1957). Leaf miners are serious pests that reduce growth.

Witches' Broom

Witches' broom, a virus disease of black locust, can be transmitted through grafts. The degree of brooming is varied and is serious only among seedlings and small saplings. Leaflets are smaller than normal and drop early in autumn, petioles are greatly shortened, and axillary buds are transformed into a prolific number of short, succulent branches. It is the continuing production of these branches which forms the broom. The virus may arrest terminal root growth, as brooming occurs where roots have been repeatedly cut. It is, thus, a potential problem in cultivated stands (Grant, Stout, and Readey, 1942).

Fomes Rimosus

Extensive heart rot in older living trees is common in black locust throughout its range. Entrance of this rot often takes place through locust borer wounds (Boyce, 1938). Conks on living trees indicate extensive decay.

Frost Effects

Black locust has been reported to be frost-hardy, perhaps due to the low starch, high sugar conversion in the bark in autumn. In other seasons, the starch in black locust bark is unusually high (Siminovitch and Briggs, 1954). Although frost-hardy, seedlings in exposed gullies may not be resistant to frost heaving. In the Tennessee Valley, large planting stock should be used and must be mulched, as frost heaving is inversely proportional to seedling size. Whether trees are planted in winter or spring has no apparent effect (Cooper, 1940). For the general run of sites, however, mortality from frost heaving probably does not exceed 5 percent.

Rodents

Some little damage is attributable to rodents (Minckler, 1941a).

YELLOW-POPLAR

Yellow-poplar is a tree of paradoxes, especially in name. It is not a poplar; nor is its botanical name "tulip-bearing lily tree" accurate, as it is neither related to tulips nor lilies. Yellow-poplar, one of the principal replacements for American chestnut, is a highly desirable tree, especially on moist sites.[11]

Growth

Southern Appalachians

Yellow-poplar diameter growth in coves in the northern zone of the Southern Appalachians averages 20 inches dbh at maturity on land with SI 100 (Creasy, 1954). In the southern zone diameter growth from 12 to 20 inches takes but 20 years, during which time volume increases 5 times, and net value 30 times; since a 12-inch tree usually has 2 logs of number 3 grade only, while a 20-inch tree will likely have 4 logs, one of which is select grade, another number 1, another number 2, and only one number 3 (Campbell, 1948, 1949). Frothingham (1941) reports a 30-year-old plantation averaged more than 40 feet in height and 7 inches dbh on the Biltmore Estate.

In a study by Fechner (1951), small sawlog trees made up one-fourth of the number of stems but only 5 percent of the stand volume. If left to grow 5 years, the trees from whence these logs come would increase in value at the rate of 6 percent annually. If left 10 years, the interest rate would equal 8 percent per annum. Dominants less than 16 inches, therefore, are needed for future crop trees, and should be retained.

As a result of a silvicultural cleaning, a cove-site stand of 40 MBM, half of which was overtopped yellow-poplar that invaded after clearcutting and fire, appreciably increased in diameter and in the number of desirable dominants. Ten-year growth on cleaned plots was 1.7 inches dbh and on uncleaned 1.4. Desirable dominants numbered 140 per acre on treated and 90 on untreated areas (Abell, 1935).

Other reports of yellow-poplar growth include (1) an abandoned field in Maryland where second-growth trees attained 90 feet in 3l years, (2) a plantation on a bench in an eroded field which grew 8 inches dbh and 35 feet tall in 13 years, and (3) second-growth in a Southern Appalachian Mountain cove with 48-year-old trees 110 feet tall and up to 26 inches dbh (McCarthy, 1953). In the mountains of north Alabama, 4-year diameter growth varied according to site as follows: high vigor, 1¾ to 2¼ inches; medium vigor, 1¼ to 1¾ inches; and low vigor ¾ to 1¼ inch (Burkle and Guttenberg, 1952).

Sandy soils, as on the Cumberland Plateau of Tennessee, appear to be suitable only if free from excessive drying. Whether derived from limestone, and hence calcareous. or sandstone appears to make

[11] **Silvical Characteristics of Yellow-poplar** (Olsen, 1969) is an excellent recent publication.

little difference upon growth, apart from texture-moisture relations dependent upon soil genesis. Friable shales, for instance, give rise to thin soils that are unproductive for yellow-poplar.

Piedmont

Yellow-poplar is, without exception, the most desirable deciduous species in the Piedmont province. Here it is rather demanding of its requirement for deep, fertile, well-drained loam or sandy loam soils. Yellow-poplar trees fail to maintain themselves on heavy clay or sandy soil, upper or southwesterly slopes. In better cove sites, growth will approach 10 feet in 2 years.

Stoehr (1959) reports a 22-year-old natural stand in Georgia with 4 MBM, annually growing 180 cubic feet per acre. Trees averaged over 10 inches dbh and 64 feet tall. A loblolly pine stand on a similar site had one-half the volume, less than one-half the growth, and contained trees averaging only 9 inches dbh and 47 feet tall (Fig. 32).

It is believed many sites could produce such high volumes of high value yellow-poplar veneer and saw logs. For instance, a 17-year-old plantation, originally spaced at 6x6 feet on a colluvial bottom, had a basal area of 150 square feet per acre, 6-inch average dbh, 70-foot heights for dominant trees, and 30 cords per acre volume. Border trees, not included in the averages above, were up to 14 inches dbh, and had they been included would have raised the volume to 60 cords per acre. (This is evidence of the competition of close spacing among trees of the type) (Nelson and Jackson, 1956).

Figure 32. *A 22-year-old yellow-poplar stand in the Georgia Piedmont.*

Site Index

Yellow-poplar clearly prefers deep, permeable, well-drained, but moist soil in coves which shelter the soil and trees from drying winds.

Poorly drained soils are too wet for sustaining adequate growth. Hence, for this species, site index is directly related to depth to tight subsoil and, to a slightly less degree, to depth of the A_1 horizon of organic-enriched mineral soil in undisturbed profiles. Friable soils less than 24 inches deep resting on a dense subsoil are poorer than averge yellow-poplar sites. In the Central States where site indexes range from 56 to 95—not too unlike the Southern Appalachians—average sites have more than 3 inches of A_1 horizon; and site index increases 3 points for each inch in depth of A_1, to a maximum of 8 inches (Auten, 1945). Site index is generally 10 to 15 points higher for yellow-poplar than for oaks on the same sites. Yellow-poplar is superior to white pine on the best sites only, while other species also surpass it on the lowest quality sites (SI 70 to 80). Sweetgum growth is probably equal to that of yellow-poplar on upland residual soils, but the association of the two species is infrequent (Olson and Della-Bianca, 1959). Yellow-poplar occurs widely enough with a sufficient range of site indexes to serve as an index species for growth potential of other major trees (Fig. 33).

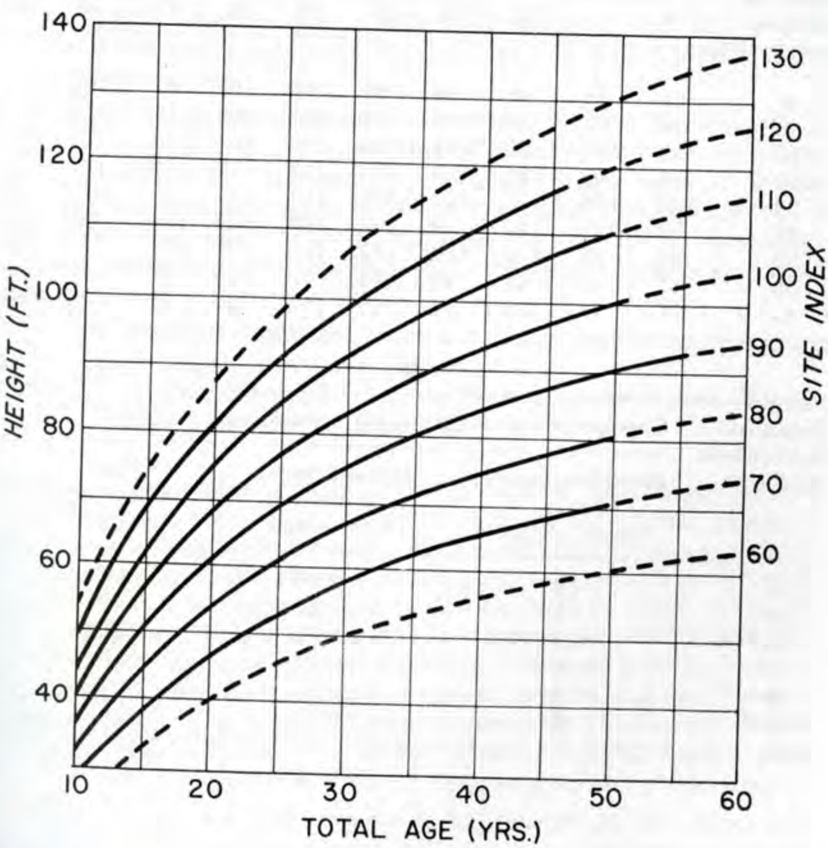

Figure 33. *Site index curves for second-growth yellow-poplar* [*Appal. For. Exp. Sta., 1934*].

SI curves developed by Beck (1962) are derived from the formula for the Southern Appalachians:

$$\text{Log SI} = \text{Log Ht (feet)} - 9.158\ (1/50 - 1/\text{age})$$

for the Piedmont:

$$\text{Log SI} = \text{Log Ht (feet)} - 6.503\ (1/50 - 1/\text{age})$$

For southern New Jersey, Phillips (1966) developed Table 22, in which depth to mottling, depth to tight subsoil, clay content of subsoil, topographic, and surface soil drainage control 67% of the variation in SI.

Table 22. *Site index for yellow-poplar on soils of the inner Coastal Plain of New Jersey*[1] [*Phillips, 1966*]

A

Depth to mottling (inches)	Percent of clay content of B_2 horizon (or 24- to 36-inch depth)									
	5	10	15	20	25	30	35	40	45	50
0	91	94	96	98	100	101	102	101	100	98
5	94	97	100	102	103	105	105	105	104	102
10	98	100	103	105	106	108	108	108	107	105
15	100	102	105	107	109	110	110	110	109	107
20	100	103	105	107	109	110	111	111	110	108
25	99	101	104	106	108	109	109	109	108	106
30	95	97	100	102	103	105	105	105	104	102
35	87	90	92	95	96	97	98	98	97	95
40	77	79	82	84	85	87	87	87	86	84

B

Depth to tight subsoil (inches)	Topographic position and surface drainage		
	Good bottomland sites lower slopes	Mid and upper slopes and upland sites	Poor bottomland sites
10	−23	−26	−30
15	−16	−20	−23
20	−10	−13	−17
25	− 3	− 7	−11
30	+ 3	− 1	− 4
36-60[2]	− 8	−11	−15

[1] First obtain base value in A; then correct as indicated in B. Estimated site index is the result of adding these two values.

[2] Includes plots with no tight subsoil within the 5-foot zone sampled.

Other Observations

Tree Grades - Tree grades can give a fairly accurate estimate of the value of second-growth stands. Yellow-poplar log grades 1, 2, and 3, for instance, increase in value as lumber grade yields become higher with an increase from SI 80 to 120. Grade 1 showed the greatest increase in value, followed by grade 2. Grade 4 logs showed no improvement with site index (Campbell, 1959). Trees with higher grade logs, especially on high quality land, should be retained for growing stock.

Growth and Climate

Diameter and height growth rates of yellow-poplar are sensitive to rainfall, especially in late spring (Tryon, Cantrell, and Carvell, 1957). Thus, high rainfall just when meristematic cells are dividing and expanding is desirable. This correlation is for sites of rapid drainage, as on steep slopes, and does not apply to moist coves where soil moisture is seldom limiting. Suppressed trees have the same proportional radial growth ring pattern as dominants (Tryon and Myers, 1952). Temperature, both past season's and present, is unrelated to growth, and total precipitation of previous seasons does not influence growth.

Radial increment responds more than does height growth to seasonal variations in the quantities of limiting factors present, as when supplemental nutrients are applied, when light is added through thinnings, and when moisture is supplied through control of vegetative competition. This is shown by the regression, significant at the 1 percent level, obtained when annual height growth is plotted against annual radial increment:

$$Y = 13.32 + 2.35x$$

where Y = height growth in inches
and X = diameter growth in mm (Tryon, Cantrell, and Carvell, and Carvell, 1957) (Fig. 34).

Therefore, even though annual height growth is not directly related to precipitation, since radial growth is limited by rainfall, terminal response is indirectly influenced. That a previous season's climate does not bear upon the present year's growth is not an exceptional phenomenon for hardwoods; but it, like the lack of direct influence upon height growth, is in contrast to the responses upon conifers of a previous year's limiting factors of growth. For good growth over the long range, a mean annual temperature of over 48 degrees F and a growing season of at least 180 days is necessary (McCarthy, 1933). Generally yellow-poplars grow rapidly after late April, reach a peak the first half of June, and drop to very low rates by mid-July.

Because oaks and red maple radial growth is not related to rainfall, perhaps these hard hardwoods are less sensitive to low soil moisture than is yellow-poplar.

Old-growth mixed hardwoods exert modifying influences upon microclimate to the degree that utilization of available soil moisture

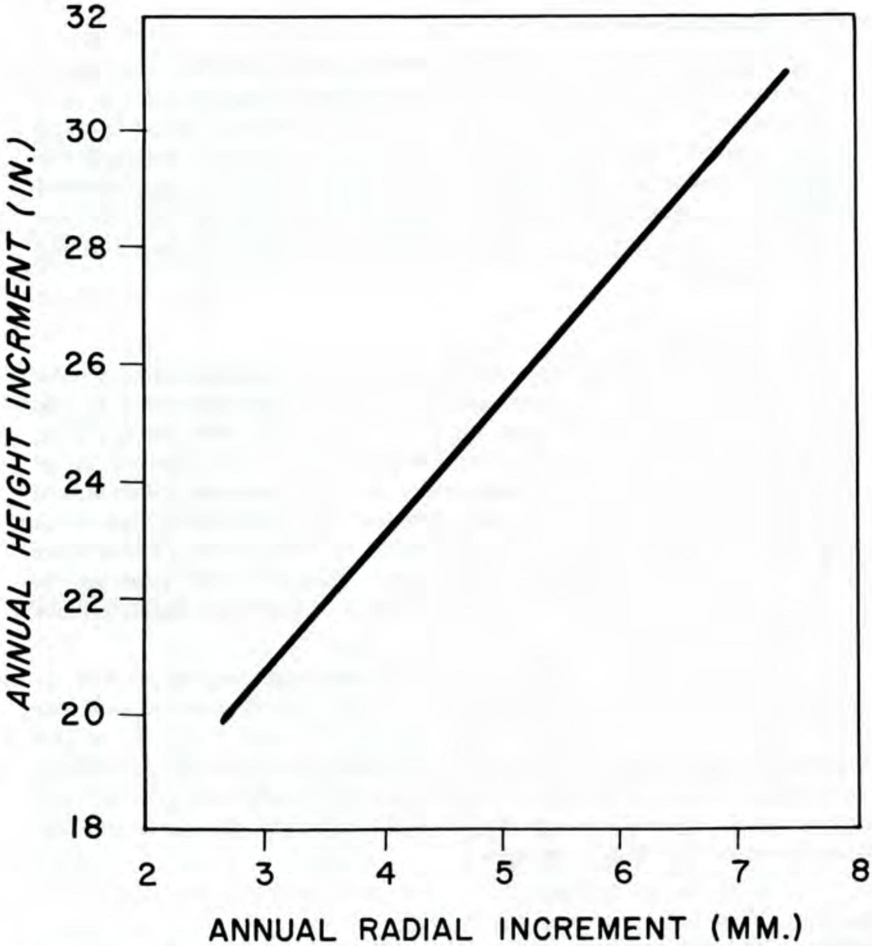

Figure 34. *The relation of annual height and radial increments* [*from Tryon, Cantrell, and Carvell, 1957*].

for growth by adjoining younger yellow-poplar is more efficient. Temperatures during the growing season are lower, with evaporation and transpiration consequently less. The difference in soil moisture adjacent to old-growth hardwoods is especially prevalent in the upper 6-inch zone where the greatest concentrations of fleshy lateral roots are found (Shipman and Rudolph, 1954).

Microbiology - While numerical counts of soil micro-flora and -fauna may have value in ascertaining the physical and chemical characteristics of individual horizons, which indirectly influence the growth of forest trees, estimates of the total number in the profile are of little value for yellow-poplar site quality interpretation. In general, however, there is an increase in the number of bacteria, actinomycetes, and fungi with increasing stages of yellow-poplar development, as observed under greenhouse conditions (Shipman, 1955, 1957). Microorganisms, including nematodes and fungi, are consistently more abundant in soils supporting yellow-poplar than in those supporting pines (Lane and Witcher, 1967).

Flooding - The need for well-drained soils which are not subject to growing-season floods is emphasized. Dormant season inundation apparently does no damage, but a single overflow of a river bottom for as little as 4 days during the growing season will kill all tops back and virtually wipe out a yellow-poplar stand. In small tanks, seedlings were able to endure 3 days of summer flooding. Mortality then set in; and extending the flood period increased mortality until all trees were dead after 14 days (SEFES, 1959). Late summer and fall rains probably do not affect growth because photoperiod and temperature become limiting factors by July.

Heartwood Color - Color of the heartwood, and the amount of it, are controlled to a certain degree by soil moisture. Ashe (n.d.) early noted that trees in fertile coves have a large core of heartwood, those in rich limestone soils have dark brownish-yellow heartwood, and trees on dry sites have small, pale yellow to nearly white interior cores. At the same time, moist sites may be xeric in behavior due to poor aeration and other physical properties (Fechner, 1951). Better sites, therefore, should be managed for this species, since a large percentage of heartwood is desirable and, for many uses, dark color is preferred.

Regeneration

Natural

As yellow-poplar is very intolerant of shade, it is most often found taking over clearcut areas and sites where catastrophes have occurred, provided seeds are available. Although seed crops are produced annually by sapling, pole, and sawtimber stands, the high basal areas (exceeding 100 to 150 square feet per acre) and the heavy layer of litter, forming a matted humus shortly after leaves fall to the ground, precludes germination and seedling establishment. As yellow-poplar is injured by even the coolest fires, burning for seedbed preparation before felling parent trees is not prescribed. When germination is adequate, low light intensity often prevents seedlings from passing from the succulent stage and they are, therefore, either killed by winter freezes or "smothered" by subsequent heavy leaf fall. Seedling yellow-poplars initiated after a fire in a young stand are also soon overtopped by sprout growth. Even staghorn sumach, sassafras, and black locust may form stands with canopies too dense for yellow-poplar to penetrate. The only shade under which the type appears to thrive is that of grass and low bushes in old-fields.

Seedbeds - As implied above, seedbed conditions affect yellow-poplar regeneration. Seedlings are more numerous on burned than unburned areas, on clearcut than partial cut areas, where leaf litter is minimal, and on skid trails than under adjacent forest stands. Better germination on mineral soil may be associated with pre-chilling to break dormancy since a layer of organic matter reduces maximum temperature, raises the minimum temperature and, thereby, reduces the temperature range. While germination on the bare *A* horizon in an open field is favorable, survival may be low due to desiccation. The inherent dryness of *B* horizons, where the *A* has been removed by erosion, also results in poor germination and survival.

Germination of seeds resting on litter under full sunlight is not dependent upon whether the organic matter is raw or decomposed. The percentage of these seedlings which survive, usually scant, also varies little between these humus types. Apparently survival is as good as it frequently is because the humus serves to conserve moisture and otherwise protect the seedlings which do germinate to a greater degree than on sites without the natural mulch. In the Piedmont, depth of A_1 or A_2 apparently is not an important influence upon seealing establishment but, in addition to the small zones where raw humus accumulates, soils poorly aerated for other reasons, or where vegetative competition is severe, do not regenerate. It seems apparent that it is necessary to expose mineral soil mechanically or by prescribed burning, and to open sites, to assure reproduction establishment.

Seed Production - Viability of seed is a subject for debate. It has been postulated both pro and con that "cones" or fuit clusters from the upper crown produce seeds of higher germinative capacity than those from lower parts. However, production rates of viable seeds at various crown elevations do appear consistent for certain trees, and cutting tests are therefore warranted before fruit collection. There is no advantage to harvesting only large cones as many small fruit have higher numbers of sound seeds (Wean and Guard, 1940).

In examining sample cones before harvest, one should look for embryos. These are present if endosperm tissue is still intact. To see the endosprm, seeds are soaked for 24 hours, imbibition of water causing germ tissue to change from a chocolate-brown to whitish color. Cones are cut on the transverse when seeds are sampled, as an abnormally low percentage of seeds near base and tip have endosperms. As few as 20 percent of the seeds may have endosperms, most of the balance having aborted after fertilization of the egg (Wean and Guard, 1940).

Yellow-poplar stands produce an abundance of seeds almost every year, frequently more than 500,000 (Tryon and Carvell, 1960). Viability, however, may be as low as 10 percent. In the Piedmont, seedfall begins about the time of leaf fall, most seeds falling in November during periods of high temperature and low rainfall. Neither relative humidity nor time of seedfall—through March—affect viability (Carvell and Korstian, 1955). In the mountains, seedfall may be a little earlier.

The number of fruit clusters for the species is directly related to dbh (Fig. 35). About 80 seeds are in each cluster (Carvell and Korstian, 1955).

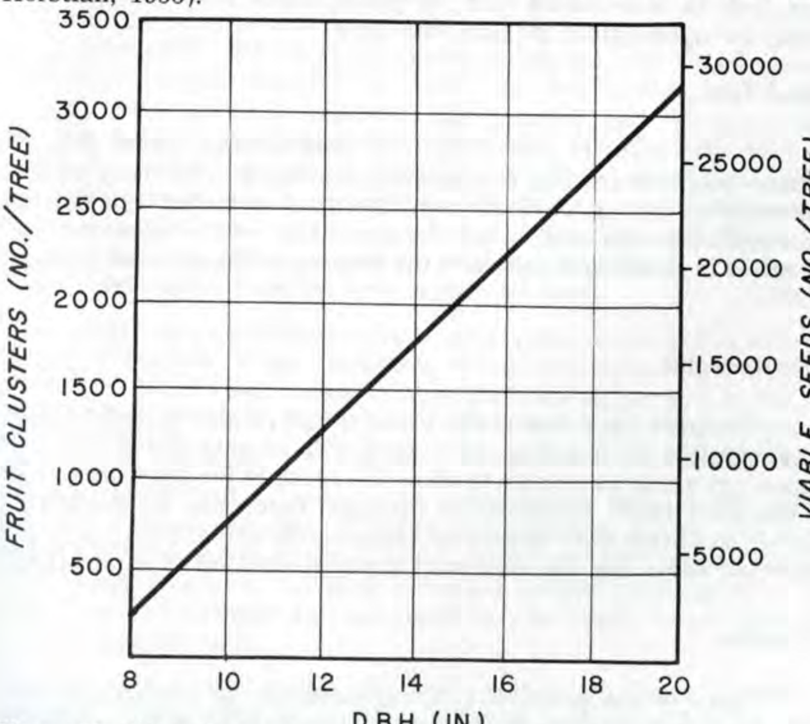

Figure 35. *The relation between dbh and the number of fruit clusters [left axis] and viable seed [right axis] for yellow-poplar [from Carvell and Korstian, 1955].*

Seed crops are heaviest on open-grown trees and upon the parts of the crown exposed to full sunlight—tops of trees and ends of branches. McCarthy (1933) observed that dry weather loosens carpels after maturing, but they are blown from the cup-shaped ring of basal scales only by comparatively strong winds. Dissemination is usually to a distance of four to five times the height at which seeds are borne. Seeds may lie viable in the soil or litter for a year before germination.

Clearcutting

Sims (1932) favors burning after clearcutting as a means of stimulating regeneration establishment, pointing out that sudden losses of yellow-poplar suffered after clearcutting in unburned areas are due to competition of the lush growth of ferns and brush that come in immediately. A dense mat of fern root 2 or 3 inches thick covers large areas.

In many areas, especially the small coves where yellow-poplar invades following agricultural abandonment, cultural measures are unnecessary, for the species is more readily established in clearings than under canopies. Likewise, about ten times as many seedlings come in on clearcut sites as on lands with stands having volumes of perhaps 5 MBM. Areas stocked to this degree can best be regenerated by clearcutting, leaving a few trees around the periphery for seed. In New Jersey and Maryland, Little (1967) suggests the need for openings of at least one acre.

Seed-Tree

If the site is too large for clearcutting—more than 10 acres—seed-tree cutting is suggested, leaving 5 to 10 trees, 14 to 20 inches dbh, per acre. Seed-tree cutting of a mixed oak-shortleaf pine-yellow-poplar stand, leaving about four of the latter per acre, resulted in good regeneration in the Piedmont (Carvell and Korstian, 1955).

Shelterwood

On good sites, especially lower northern slopes, yellow-poplar regeneration is obtained with bare soil of thin litter and when openings are large enough to allow full sunlight for one-third of a day (Minckler, 1959). Shelterwood cuttings, then, may be necessary in order to obtain that degree of exposure to the sun's rays, a later harvest removing the balance after reproduction is established.

Coppice

There is the possibility of regeneration by coppice on short rotations. Parent stumps rot quickly which could be detrimental in that little support for the sprouts is retained. This is important in areas subjected to heavy winds and sleet. The technique cannot be used in old stands (over 14 inches dbh), for only relatively young trees sprout. McCarthy (1933) reports on a coppice forest which pushed through a dense blackberry jungle to overtop seedlings and sprouts of numerous other, and shade-tolerant, species. Even seedling yellow-poplars have little chance of success where competing with their own sprouts.

Planting

Site - Good growth of yellow-poplar plantings is obtained on deep A_1 horizons—those more than 10 inches deep. Shallow zones with less than 6 inches of organic matter incorporated in the mineral soil are poor chances. Steep slopes and eroded areas should be avoided except where the surface soil is at least 6 inches deep and the subsoil loose and friable to a depth of at least 12 inches when worked. Better sites have *A* and *B* horizons of coarser texture than do poor sites, and favorable locales have considerably more organic matter incorporated in the mineral soil. Thus, the soil of a good site is characterized by its looseness, in contrast to the compact nature of poor-risk areas. Tight subsoils affect moisture supply to lower feeding roots, especially when upper horizons are dry. Too coarse surface soils dry out quickly.

The volume weight of the soil is so important that when nitrogen is determined on a volume basis, there is twice as much in the A_1 of a good site than of a poor, while on a weight basis there is no appreciable difference (Auten, 1935). The fertility concentrated in the surface soil is of little avail without adequate moisture. In loose, aerated material, fertility is built up by accumulation and decomposition of plant residues, and a cause and effect relation obtains. Thus, while yellow-poplar probably would not do well on fertile dry soil, it might be satisfactory on infertile areas if adequate moisture were available throughout the growing season. However, where available soil water is adequate, fertility will likely be favorable, too, as plant remains incorporated in the soil are largely, though perhaps indirectly, responsible for both.

Growth of yellow-poplar plantings is poor on dolomitic soils in the lower reaches of the Tennessee Valley because of their stiff *B* horizon. In friable soil, yellow-poplar plantings did as well in dry as in wet planting years; but where such soils are plastic, dry years were found only 62 percent as good as wet years (Minckler, 1943).

Minckler (1946a) recommends yellow-poplar only on the more moist sites of abandoned old-fields and pastures. North and east slopes at all elevations, lower to middle south and west slopes, coves, well-drained bottoms, and sink holes are proper planting sites. A moderate cover of brush and tall weeds may be helpful in temporarily preventing desiccation.

In an immature azonal silt loam soil in northern Alabama, survival was especially favorable on alluvial bottoms and lower and middle northern slopes and, after 2 years, some trees were 9 feet tall (Table 24). At higher elevations, most trees died (Schomaker, 1958).

Table 23. *Average Second Year Survival and Total Height with Relation to Soil Moisture and Topographic Position [after Schomaker, 1958].*

Topography	Soil Moisture	Height	Survival
	PERCENT	FEET	PERCENT
Bottom	25	5	85
North Lower	23	4	92
Middle	21	4	85
Upper	19	3	88
South Lower	20	4	84
Middle	17	3	71
Upper	14	2	61

Good growth may be attributed to the clearing of weeds for a radial distance of one foot around each tree. The close correlation of soil moisture with tree heights for this area suggests that yellow-poplar plantings be limited to bottoms, lower two-thirds of slopes of northern aspect, and the lower one-third of south-facing slopes. Adjustment will need to be made according to soil texture and the consequential influences this may have on soil moisture and, therefore, site quality.

Average survival and 5-year height growth for trees released shortly after underplanting on upper, lower, and middle slopes in a north Mississippi loess soil are:

	Survival, percent	Growth, feet
upper	54	5
lower	80	8
middle	64	8

Where unreleased, survival after 5 years was 40 percent or less and growth for the period was under 2 feet (Williston and Huckenpahler, 1957).

Table 25 gives the average height growth, in feet, of plantations of yellow-poplar and other species recommended for the Southern Appalachians for dolomitic, limestone, and shale underlain sites.

Coastal Plain - Yellow-poplars have been successfully planted in the Coastal Plain. As in other provinces, it is essential that seedlings be placed on sites with extremely good moisture conditions—always damp, but never waterlogged—and free from competition. Excellent survival and growth may then be had.

Spacing - Planting at 8x8 foot spacing is recommended, and some site preparation is suggested. Hoeing a spot with a diameter of 2 feet, in the center of which a 1†0 seedling is planted, should expedite establishment of the plantation. It is noteworthy that the successful early Biltmore plantations near Asheville, North Carolina, were with 3-year-old stock (Frothingham, 1961). The possibility of using a checkerboard planting pattern of yellow-poplar with black walnut at a ratio of 2:1 spacing is suggested by Minckler (1946b).

While the densest stands of sassafras should not be planted to conifers in the mountains, hardly any stands are too dense for yellow-poplar, according to Minckler (1941). Sparse stands of young nearby even-aged shortleaf pine with large spaces between trees occupied by broomsedge can also be interplanted successfully with this species.

Stock Size - Recent tests define a minimum size for plantable yellow-poplar seedlings: seedlings below ¼-inch at the root collar are poorer in survival after 3 years than those ¼-inch or larger, and seedlings below 1/5-inch are not acceptable. Intermediate sizes are marginal (Rodenbach and Olson, 1960; Limstrom *et al.*, 1955).

Seed Source - It might appear that seeds should be collected from the southern part of the range for planting in the mountains as early height growth initiation is a characteristic of warmer seed-source areas. Because the mountain areas have a short growing season, growth of planted trees of this provenance begins later in the spring, regardless of the climate of the area to which they are moved (SEFES, 1959). However, this early growth advantage of a warm climate seed source is cancelled out by the early inception of dormancy in cold climes. However, as the beginning of dormancy is also correlated with the date of the first killing frost at the point of origin, moving northern provenance stock southward is not advantageous. Hence, total height may not differ significantly for stock from many areas within and from out of the planting zone (Sluder, 1960). No other characteristics appeared associated with the climate of the source.

Survival varies significantly by seed source, but this is not related to geography. Illinois, Mississippi, New York, Ohio, and local stock did as well or better than other mountain-originated trees in Sluder's North Carolina test. Since the lowest survival percentages were about 80 percent, and the high 96 percent, and because of the lack of latitudinal relationships, there seems no justification for seeking out origins on the basis of survival or growth. One might disfavor seeds from more southern climes that produce stock which breaks dormancy earlier in the spring and, as a result, is damaged by late spring frosts.

Propagation - Summer cuttings from twigs of lower branches of codominant trees, 30 years or older, are effective means of reproducing yellow-poplar. Cuttings should be from superior phenotypes, of course. Wounds on two sides at the base of the cutting are made by removing a 1-inch slice of bark. Rooting is initiated in greenhouses or shade sheds with mist provided (Nelson, 1957a).

Auxins, such as indolebutyric acid in concentrations up to 75 mg per liter of water, do not stimulate rooting of yellow-poplar cuttings (Huckenpahler, 1955), but dosages of 20 grams per liter into which cuttings are dipped for 10 seconds do (Enright, 1957). A 1 percent solution of gibberellic acid applied to young stems as terminal buds opened provided a significant response in height growth in early tests. Only as much as could be held on the end of a toothpick was applied to the new shoots, or to knife-nick wounds around the stem (Nelson, 1957a). Subsequent experimentation has been unable to reproduce this response.

Another method of vegetative propagation for small stock is to longitudinally split entire seedlings, each half of which must have at least one well-developed, undamaged lateral bud. Exposed root and stem tissue is coated with lanolin and planted. The upper half is then clipped so that dominant stem growth is from buds close to the root collar (Nelson, 1957). In greenhouse work, yellow-poplar resumes growth when long-day periods are initiated after trees have been dormant (Kramer, 1936). They may then grow all winter under long-day conditions or, as Downs and Borthwick (1956) observed, stop further growth after about ten 8-hour days—much less than for most woody plants. Increasing day length to 16 hours maintained growth through a 14-week period. Zahner (1955) also reported that yellow-poplars grow well all year under long-day conditions. they make less growth and become dormant sooner under short-day than normal-day lengths. Height growth is increased by interrupted darkness after 7 hours with brief periods of light, a response which appears within 4 weeks. Yellow-poplar is probably less sensitive to the effects of darkness than are conifers.

Cuttings may be safely stored at 41 degrees F in plastic bags for 15 days (Steinbeck and Porterfield, 1967).

Direct Seeding

As a result of failures in early trials of direct seeding, planting is usually recommended as more satisfactory (Korstian and MacKinney, 1931). Recent tests, however, reopen the matter for consideration. Direct seeding cannot yet be universally recommended but, where practiced, sowing rates for flat topography of 120,000 seeds per acre or 60 to 80 per spot are suggested to obtain 800 seedlings per acre. This great number is required because of poor viability. Since many more seeds—six times as much in one case (Clark, 1958)—germinate on west-facing slopes than east-facing, rates of sowing should be adjusted accordingly. Sixty thousand seeds per acre on drier sites and 200,000 seeds per acre on wetter eastern aspects are within conservatively safe limits. Following germination, survival is likely to be superior on the moist areas. Screen protection of seed spots, spring seeding (rather than fall), and covering with 1/8 inch of soil are recommended (Sluder, 1964). Disking before seeding is not recommended unless humus prevents contact of seeds with mineral soil. Seeds will remain viable for as long as four year in forest litter (Clark and Boyce, 1964).

Intermediate Management

Competition Control

Control of overtopping vegetation is essential for plantation establishment. Yellow-poplar crop trees more than 5 feet tall are generally able to stay ahead of competing trees after a single treatment (Buell, 1940). Minckler (1946b) states that yellow-poplar is more shade-tolerant than either shortleaf or white pines. Consequently, where the conifers are not too dense and not too much taller than the yellow-poplar, intensive cleanings may not be essential. Crown classes of yellow-poplar for which weeding is recommended are given in Table 27. It is suggested that sassafras need not be cut in stand improvement operations because of its soil-improving properties and the beneficial nature of its shade.

Thinning

Thinning is not recommended for non-merchantable sapling-size stands as only a fair response to release of trees this size is obtained. An exception, of course, is where intermediate management requires some cutting to avoid stagnation of potential crop trees, although this is hardly conceivable, or where watershed management necessitates reduction of the transpiring crop. Good, vigorous dominants will not require release as they can easily outgrow threatenting canopy competition (Downs, 1946). Otherwise the species responds well to release (Shearin, Bruner, and Loadholt, 1970).

Pole-size stands should be thinned from below to provide a fair response to residual trees and enable salvage of stems likely to be lost. Thinning from above is not desirable as the species, sensitive to suppression, may respond slowly when medium-vigor trees are released (Downs, 1946). Death may actually seem inevitable to suppressed trees with small crowns at time of thinning; but, after release, crowns increase 20 to 50 percent of their height and 2 inches dbh in 10 years. Yellow-poplar must overtop its associates to maintain its rapid initial growth rate. As this species is very susceptible to frost injury, particularly with stems of medium vigor, trees growing in frost pockets or on poor sites, especially in the northern part of the region, should not be released by thinnings.

A thinning guide for yellow-poplar is given in Table 24. Simplified marking guides, developed by Burkle and Guttenberg (1952) for north Mississippi, but probably applicable elsewhere in the upland forests of the South, are discussed previously (Table 25).

Table 24. *Yellow-Poplar Thinning Guide. Basal Areas Include All Trees 5 Inches D.B.H. and Over* [*after Morriss, 1958*].

	Leave basal area (sq. ft.) for site index						
Age	60	70	80	90	100	110	120
25				51	57	62	66
30			54	62	68	74	79
35		54	64	72	80	86	91
40		62	73	82	90	96	102
45	55	70	82	92	100	107	113
50	62	78	90	100	110	117	124

Table 25. *Crown and Bark Characteristics of Yellow Poplar by Vigor Class* [*from Burkle and Guttenberg, 1952*].

High Vigor	Medium Vigor	Low Vigor
Bark: Corky but shallowly ridged, light ash-grey. Diamond shaped fissures display light-colored inner bark.	Bark: Thicker, Ash-grey. Ridges more pronounced. Some inner bark visible in fissures.	Bark: Thick. Dark grey. Fissures deep and very pronounced. No inner bark visible.
Crown: 2/3 or more fully formed and without close competition Full and healthy, composed preponderantly of small ascending leaders and twigs. Foliage abundant and lustrous. Sharp pointed crown an important indicator.	Crown: 1/2 or more fully formed and without close competition Crowns notably less full and less pointed than those of high vigor trees. Crown limbs are larger and do not ascend as steeply as in high-vigor crowns.	Crown: Small end poorly formed. Thinly foliated. Branches relatively dark in color and spreading rather than reaching in aspect.

The techniques are appropriate for yellow-poplar, employing the photos of Figure 36 showing bark characteristics of high, medium, low vigor, and decadent trees.

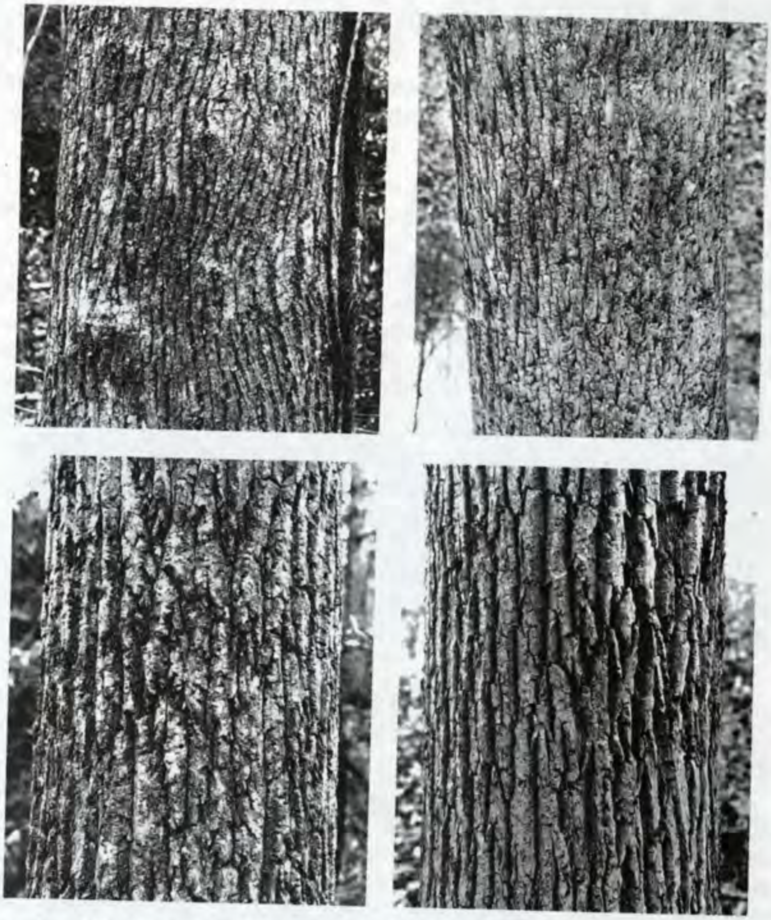

Figure 36. *The bark of upper left and right, high, medium, and lower left and right, low vigor, and decadent yellow-poplar trees [from Burkle and Guttenberg, 1952].* (USFS Photos).

Wood Quality

Specific Gravity - Yellow-poplar wood varies appreciably, depending upon tree ages. Average specific gravity for old growth—trees from 150 to 300 years old—is 0.349 to 0.378. For those from 70 to 150 years, it is from 0.379 to 0.430. Second growth trees less than 70 years old are not much different from younger old growth, but the average is of a narrower range: 0.381 to 0.409 (Paul and Norton, 1936). Thus for light, soft wood, old trees retarded through competition are selected. Younger trees that have retained fairly rapid rate of growth, either in the virgin forest or from second growth, are used for hard, heavy wood. This is in contrast to frequent observations that fast growth provides lightweight wood.

Epicormic Branches and Thinning - Blemishes of epicormic branching are probably more degrading to yellow-poplar than any animal or pathogenic pest. The small knots left by repeated sprouting, while sound, discolor the wood and lower the grade. Since thinning encourages sprouting, it should be postponed until trees are more than 20 years old for production of high quality logs. If quality is not sought, increase in volume by thinning may offset quality losses.

Thinnings for wood quality should be light, as the valuable butt log clears of epicormic sprouting more rapidly than when severely released. However, even with heavy thinning, epicormic branches will not persist on the two lower logs for more than 10 years following release. Stems with the most and largest sprouts should be harvested in early intermediate cuts. Jemison and Schumacher (1948) have a technique for computing epicormic branches based on volume cut, original stand volume, and tree height and log condition.

Sprouts arise when and where needed to restore losses of lower crowns suffered by natural pruning of crowded trees. After crowns are shortened, sprouts tend to arrest or even reverse the process of natural pruning. The water sprouts are rather temporary where trees remain in crowded situations, but persist where neighboring trees competing for sunlight are removed (Wahlenberg, 1950). Sprouts on released trees previously suppressed may prevent death and aid in restoring vigor for normal growth.

Trees equally crowded on all sides sprout most on the warmest side—south to southwest. Otherwise most sprouts are on the open side—where branches are longest and in the upper part of the pruned bole. Few are in the crown.

Intermediate and suppressed trees sprout more than do dominants and, in the case of dominants and codominants, sprouting increases with the degree of release. Trees with many branches have many more upon release. There is evidence of inherent susceptibility to epicormic sprouting (Wahlenberg, 1950). Smith (1967) noted the relation of visible dormant buds to tree diameter and, for this species, the greater number of such buds on the upper log. He (1965) and Fenton and Pfeiffer (1965) consider epicormic branching less important than for most other species.

Growth regulating hormones have been tested for controlling and killing epicormic branches without otherwise damaging trees, but thus far none has been effective.

Fertilization

Yellow-poplar responds well to fertilization with nitrogen and phosphorus on well-drained bottoms which may overflow during dormant seasons. The growth stimulation probably is important in enabling seedlings to get above the critical, but as yet undetermined, height below which growing season flooding is injurious. Nitrogen dosages of 200 pounds per acre and P_2O_5 and K_2O at 100 pounds per acre each were suggested by Cummings (1941).

Tests for the Southern Appalachians are lacking and in other areas have not proceeded sufficiently to suggest nutrient amendments as a practice. However, of all the southern forest trees, this species appears most promising for early use of commercial fertilizers for stimulating growth (Fig. 37). when 1-year-old

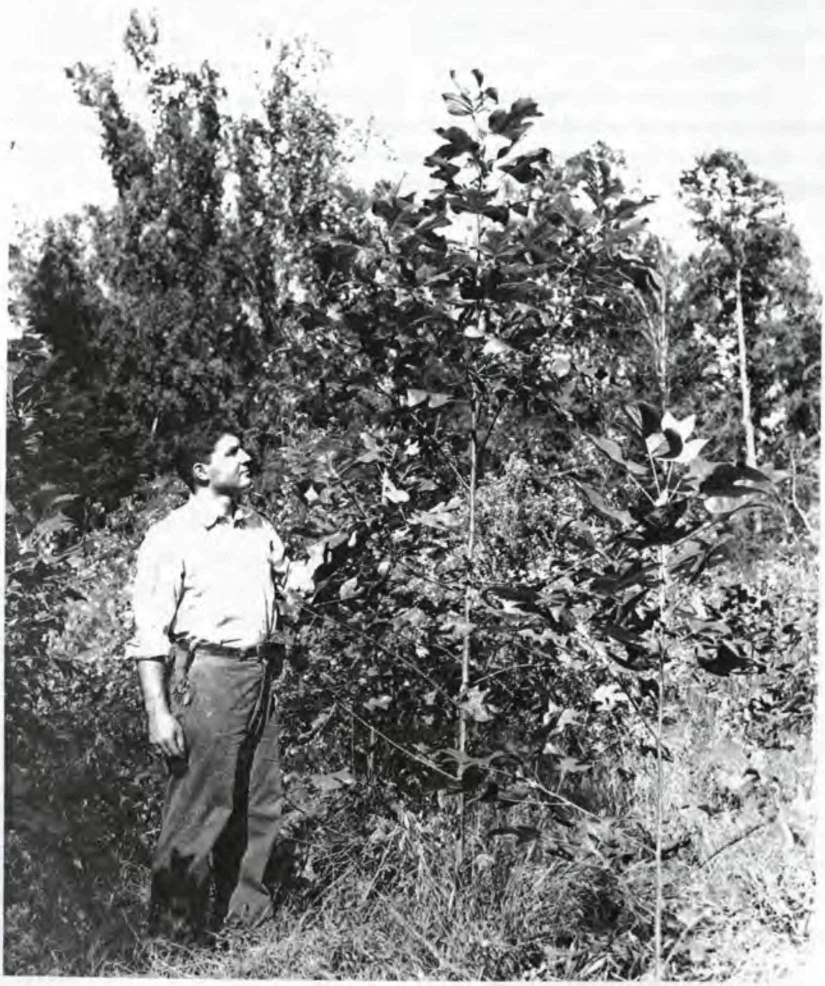

Figure 37. *Fertilized yellow-poplars grew 7 feet in the first 2 years after outplanting.* (USFS Photo).

yellow-poplar seedlings were planted in a stream bottom in the Georgia Piedmont and fertilized in May with 0, 250, 500, and 1000 pounds per acre of diammonium phosphate (20-52-0), first- and second-year observations showed increasing height with increasing fertilizer rates. All treatments (combined) were significantly (1% level) taller than controls. The 500 and 1000 pounds per acre rates gave greater response than 250 pounds per acre, but no significant difference occurred between the two higher rates. Height growth was 0.5 foot for check and 1.9 feet for the 1000 pounds per acre rate.

Treatment did not affect survival through the second growing season (McAlpine, 1959, 1959a).

Elsewhere in the Piedmont, 1-year-old stock was fertilized at time of underplanting in a pole-size pine stand. The magnesium ammonium phosphate pellets placed in holes adjacent to the planting slits had appreciably stimulated growth by the end of the first year in the field.

Symptoms of deficiencies in nitrogen, phosphorus, and potassium have been described by Ike (1968). Growth responses to N fertilization are good when leaves contain less than 2 percent of that element.

Injurious Agents

Glaze

Glaze is a serious problem with yellow-poplar in the Southern Appalachian Mountains. Forming as cold rain contacts objects when temperature is below freezing, it is most severe when accompanied by strong winds. The ice weighs down branches and main stems on the windward side which, when frozen brittle, easily crack. Broken tops cause permanent crooks and damaged trees are made vulnerable for attack by insects and disease. Branches stripped of leaf-bearing twigs result in reduced growth for many years.

Dominants and codominants are frequently broken and trees on heavily thinned plots are most susceptible to injury: understory trees receive protection and are only infrequently damaged (Carvell, Tryon, and True, 1957). To keep damage to a minimum in areas subject to glaze, evenaged stands are maintained, with light crown thinnings that remove less than 30 percent of the volume. Sanitation and improvement cuts should follow storms to remove damaged material. Hardwoods sometimes suffer more than conifers due to branching habits, even though the latter have ice-retaining needles which contribute heavy loads when weighted with ice.

Heavy snow weights and breaks tops in second-growth yellow-poplar stands 20 to 40 years old, enabling the introduction of top rot fungi. The species is one of the most susceptible to this injury, over 90 percent of the stems having active decay following breakage. Breaks at points where tree stems are less than 2 inches in diameter heal quickly and do not expose the interior core to heartwood-rotting fungi as the heartwood ends at about the 2½- to 3-inch diameter point. However, when tops are broken, it is generally further down the stem. Most snow damage is to low-vigor dominant and suppressed trees. Pole and sawtimber stands have more snow-break and top rot than smaller trees because of the rigidness of the wood, breaking rather than bending under strain. Saplings, conversely, are bent, not broken.

Disease

Yellow-poplar is relatively free from destructive diseases. The principal heartwood-rotting fungus, as reported by Roth (1941), is *Collybia velutipes.* It grows upward at a rate of 1 to 4 inches per year and downward 4 to 10 inches beyond an entrance injury, extending 2 to 4 feet in 4 years. Decayed trees should be removed in all improvement cuttings or thinnings, but special harvests are not believed necessary unless more than 25 percent of the stems are infected.

Pocket rots, caused by the shoestring-forming fungus *Armillaria mellea,* dissolves wood in the region of the medullary rays, leaving irregular cavities. It occasionally attacks roots. The soft dark-brown or black heartrot of *Hypholoma* sp., the honeycomb pocket rot of heartwood which results from *Polyporus cerifluus* infection and a dark gray to black butt rot attributed to *Trametes malicola.* also attack yellow-poplar.

Vigorous young yellow-poplars recover from cankers caused by *Nectria magnoliae.* Trees with the target-like growth on the trunk, by which the disease is readily identified, can fairly safely be selected as crop trees and need not be removed in early harvests as long as diameter growth exceeds ½ inch every 5 years. For cankers to heal over, trees must be sufficiently vigorous to grow at least this fast (Nelson, 1940).

Ceratocystis coerulescens causes a common sapstain in hardwood logs and lumber. While not a seriously aggressive pathogen, large yellow-poplar trees have been killed by it in 2 to 3 years (Roth, Hepting, and Toole, 1959).

A *Myxosporium* canker has attacked yellow-poplars planted under less desirable species in northern Mississippi. The disease may be associated with drought in these upland soils (Williston and Huckenpahler, 1957).

Yellow-poplar dieback deserves mention here, even though its presence has been noted only in the Piedmont and Coastal Plain. A *Myxosporium* fungus or *Xanthomonas* bacterium may be responsible (Johnson, *et al.,* 1957). Symptoms are chlorotic atrophism of leaves, sparse crowns, twigs and branches dying back, ellipsoid to elongate trunk and branch cankers, and trunks with epicormic sprouts. The epicormic branches die, leaving lateral cracks in the bark which give trunks the appearance of having frost shake. The disease in saplings progresses inward and downward. In older trees the pattern is not so well set. Most infection is to overtopped trees of poor vigor on upland sites. Death may occur within 2 years after infection.

Other Injuries

Other injuries include sun scalding of the thin bark of young trees and frosts that kill back new growth. Grazing, if permitted, is severe on the succulent twigs and smaller branches.

Fire - Yellow-poplar seedlings and saplings are among the most susceptible trees to fire killing because of their thin bark. When the bark of larger saplings reaches one-half inch in thickness, it is sufficient to insulate the cambium and the species becomes rather fire-resistant. Rot-causing fungi that enter through fire scars of larger trees are a chief cause of concern. Almost all trees with exposed wood from fire injuries contain decay, much of which originates from infections by *Armillaria mellea, Hypholoma* sp., *Polyporus* spp., and *Polystictus hirsutus.* Fungus infection is within scars that have completely healed over.

Insects

Columbian timber beetles (an ambrosia beetle) are the most injurious insects to yellow-poplar. Tulip tree soft scale may be found in great clusters on branch bark, killing limbs, but nothing more. Leaf-feeding aphids, maggots, and the caterpillar of a moth feed on trees of this species, but do little damage.

Birdpecks

Birdpecks, occuring on the bole surface, appear as black spots in tangential lines when viewed from the end of a bucked log. Old peck holes occlude with callus tissue. Fortunately, some trees appear immune to peck, while others are repeatedly attacked (Fig. 38).

Figure 38. *Birdpeck on surface* [*left*] *and end* [*right*] *of yellow-poplar log* [*from Fechner, 1951*].

Discolor

Defects in yellow-poplar wood not necessarily arising from disease and bacteria occur in healthy trees following wounding. Dark discoloration, for instance, takes place behind broken branches, broken tops, fire scars, insect injuries, bruises, and other logging injury (Roth, 1950). Common non-decay discolorations result from oxidation of chemical compounds in the tissues, and call for careful logging.

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APPENDIX

Common and scientific names of species mentioned in the text.

Trees and Shrubs

Common name	Scientific name
Alder, white	*Alnus rhombifolia* Nutt.
Bayberry, southern	*Myrica cerifera L.*
Blackgum	*Nyssa sylvatica* Marsh.
Crabapple	*Malus* spp.
Dogwood	*Cornus florida* L.
Gallberry	*Ilex* spp.
Haw	*Crataegus* spp.
Hickory	*Carya* spp.
Holly	*Ilex opaca* Ait.
deciduous	*Ilex decidua* Walt.
Laurel, cherry	*Prunus caroliniana* Ait.
Locust, black	*Robinia pseudoacacia* L.
Maple, red	*Acer rubrum* L.
Oak, black	*Quercus velutina* Lam.
blackjack	*Q. marilandica* Muenchh.
laurel	*Q. laurifolia* Michx.
post	*Q. stellata* Wangenh.
red	*Q.* spp.
southern red	*Q. falcata* Michx.
white	*Q. alba* L.
willow	*Q. phellos* L.
Persimmon	*Diospyros virginiana* L.
Pine, loblolly	*Pinus taeda* L.
longleaf	*P. palustris* Mill.
pitch	*P. rigida* Mill.
pond	*P. serotina* Michx.
shortleaf	*P. echinata* Mill.
slash	*P. elliottii* Engelm.
sonderegger	*P. sondereggeri* H. H. Chap.
Virginia	*P. virginiana* Mill.
white	*P. strobus* L.
Redcedar, eastern	*Juniperus virginiana L.*
Rhododendron	*Rhododendron maximum* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Sourwood	*Oxydendrum arboreum* (L.) DC.
Sumac	*Rhus* spp.
Sweetgum	*Liquidambar styraciflua* L.
Sycamore	*Platanus occidentalis* L.
Titi	*Cliftonia* spp.
Waxmyrtle	*Myrica cerifera* L.
Yaupon	*Ilex vomitoria* Ait.
Yellow-poplar	*Liriodendron tulipifera* L.

Vines

Blackberry	*Rubus* sp.
Cherokee rose	*Rubus* sp.
Clover rose	*Rubus* sp.
Grape	*Vitis* sp.
Honeysuckle	*Lonicera* sp.
Huckleberry	*Vaccinium* spp.
Poison ivy	*Rhus radicans* (L.) Ktze.
Smilax	*Smilax* sp.
Trumpet creeper	*Campsis radicans* (L.) Seem.
Virginia creeper	*Parthenocissus quinquefolia*
Wild azalea	*Rhododendron* sp.

Grasses and Legumes

Bermuda grass	*Cynodon dactylon*
Lespedeza	*Lespedeza* spp.

Insects

Moth, cone	*Dioryctria* spp.
Nantucket pine tip	*Rhyacionia frustrana*
seed-eating	*Laspeyresia* spp.
Sawfly, pine	*Neodiprion pratti pratti*
	N. abbottii
	N. hetricki
	N. taedae taedae
	N. taedae linearis
Weevils, reproduction	
Pales weevil	*Hylobius pales*
	Pissodes nemorensis
	Pachylobius picivorous

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